AD-A167 728 EFFECT OF COMPOUNDING AND MIXING VARIABLES ON THE PHYSICAL PROPERTIES OF.. (U) ARMY BELVOIR RESEARCH AND DEVELOPMENT CENTER FORT BELVOIR VA.. P TOUCHET ET AL. 1/1

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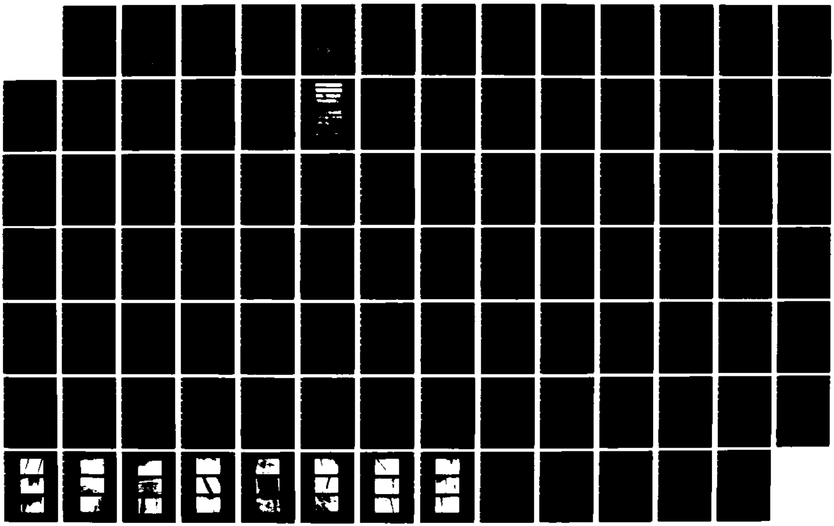

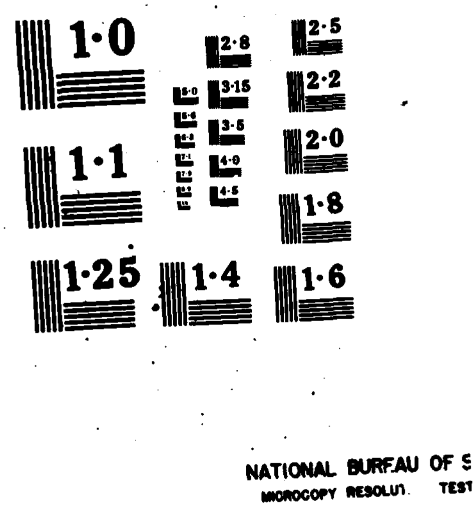
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Report 2428

Department of the Army
Belvoir Research and Development Center
Ft. Belvoir, Virginia 22060-5606

AD-A167 728

EFFECT OF COMPOUNDING AND MIXING VARIABLES ON THE PHYSICAL PROPERTIES OF ELASTOMERIC TANK PAD FORMULATION

by
Paul Touchet
Paul Gatza
Gumersindo Rodriguez
Alan Teets
and
Jacob Patt

Phase I Technical Report
August 1982 to August 1983

January 1986

US ARMY
TROOP
SUPPORT COMMAND
BELVOIR R&D CENTER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Processing studies were conducted on styrene-butadiene rubber (SBR) and natural rubber (NR) compounds typical of those used in the fabrication of tank track pads. The effects of purposely-implemented alternations in formulating and mixing of the compounds were ascertained through visual examination of ingredient dispersion and physical/mechanical testing of vulcanized samples obtained for each variant/rubber combination. Results were analyzed in terms of the ultimate positive or negative impact upon quality and expected performance of the end items.

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PREFACE

The Rubber/Coated Fabrics Research Group; Materials, Fuels and Lubricants Laboratory of the Belvoir Research and Development Center; Fort Belvoir, Virginia; prepared all rubber compounds, performed all tests, and prepared this report, as tasked and assigned by the Tank Automotive Command (TACOM), Warren, Michigan.

Joseph O'Gurkis, Eric C. Vasey, and John B. Vollmer prepared test specimens and performed most of the laboratory testing, and Donovan Harris and Dennis Higgins conducted the Scanning Electron Microscope (SEM) studies and provided the photographs used in rating elastomeric compound dispersion.

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ILLUSTRATIONS

TABLES

EFFECT OF COMPOUNDING AND MIXING VARIABLES ON THE PHYSICAL PROPERTIES OF ELASTOMERIC TANK PAD FORMULATIONS

I. INTRODUCTION

1. Subject. This report details investigations conducted and results obtained in efforts to determine the extent to which the ultimate physical properties (static and dynamic) of typical tank pad formulations are affected by variations in mixing procedures, accuracy of weighing of ingredients, overloading and underloading of a Banbury mixer, substitution with different forms of certain chemicals, and other compounding and mixing variables.

2. Background. Historically, performance in the field of elastomeric components of track assemblies of vehicles such as the M-60 tank and M-1 tank has been poor, with service life expectancy for the M-60 tank limited to as high as 2000 to 3000 mi on pavement and as low as 300 to 400 mi in off-the-road service, whereupon replacement is necessary. The M-1 track has an average life ranging from 600 to 1000 mi. Since these vehicles must be capable of deployment and movement over all types of terrain and environmental conditions, the rubber track shoes are exposed to factors which significantly accelerate wear. The configuration of a typical track assembly is an obvious factor contributing to the accelerated degradation. Unlike tires, wherein a continuous band of rubber, theoretically, has line contact with the terrain (usually smooth), tank track pads are designed for total contact with the ground but actually encounter varying degrees of intermittent contact with terrains ranging from relatively smooth to broken and irregular, often containing rocks, hard and soft soil agglomerates, organic debris, and other penetrating objects. Therefore, performance characteristics for a tank track pad are significantly different from those of a tire. In the track pad, a high degree of resistance to abrasion, heat build-up, tearing, chunking, and chipping of rubber is requisite.

Optimization of the above dynamic properties as well as the usual basic properties (tensile strength, elongation, hardness, etc.) can only be achieved through the choice of the quantity and type of compounding ingredients used with the base polymer or polymers and must be closely adjusted and controlled. Likewise, processing (such as the mixing of the ingredients) must be monitored to insure compound uniformity and absence of any deterrent to proper vulcanization of the entire volume of rubber contained in the pads.

The results of TACOM-sponsored investigations conducted by Virginia Polytechnic Institute (VPI)[1] have suggested that dispersion of compounding ingredients in the Banbury mixing cycle may have a significant effect on the ultimate performance of typical tank pad vulcanizates. Examination of cross-sections of tank pads which had failed in the field using a Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Analysis (EDAX) revealed areas of agglomerates of zinc oxide and sulfur. Whether, and to what degree, these observed inequities in dispersion have any influence on vulcanizate properties and ultimate end item performance was not fully established. Likewise, no recommendations were furnished regarding corrective measures to be taken in future procurements. Therefore, TACOM desired to investigate all processing factors which may contribute to reducing the expected service life of tank pads with the eventual objective of improving end item quality assurance. They requested the assistance of the Rubber/Coated Fabrics Group; Materials, Fuels and Lubricants Laboratory; U.S. Army Belvoir Research and Development Center; Fort Belvoir, Virginia, where complete facilities for conducting bench-scale compounding, vulcanization, and physical testing are available.

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[1] Dwight, David W. and McGrath, James E., "Formation and Failure of Elastomer Networks Via Thermal, Mechanical and Surface Characterization" VPI, TACOM Report 12498, December 1979.

II. INVESTIGATION

3. Scope. Generally, the base formulations for compounds used to fabricate tank track pads employ styrene-butadiene rubber (SBR) or natural rubber (NR). Blends of these elastomers with polybutadiene rubber (PBD) are known to have been used. However, no blends were included in this work. An evaluation plan designed to study the effects of mixing procedures, i.e., accuracy of weighing of ingredients, overloading and underloading of a Banbury mixer, use of alternate forms of certain chemicals, and variation in mixing cycles, was established. Physical tests were conducted on the cured compounds. Visual observations were performed and correlated with the test results to provide an index of the effect of the variables on vulcanizate peformance.

4. Compound Preparation and Tests Conducted.

a. Compound Preparation. The formulations shown in Tables 1 and 2 selected for preparation of the SBR and NR compounds, while perhaps not totally typical of those used in current tank track pad production, had been studied earlier[2] and were considered sufficiently representative in terms of the type and quantity of ingredients used and mixing procedure employed. The standard mixing procedures adapted for the 15 SBR-1 and 15 NAT-1 compounds, and in cases where only ingredient changes were made, are detailed as follows:

STYRENE BUTADIENE RUBBER (SBR) STANDARD MIXING PROCEDURE

The rubber is mixed in a Banbury mixer followed by a final mill mix as follows:

1. Banbury mixing procedure:

    a. The Banbury mixer is run on low speed (77 c/m) with ambient cooling water turned on full.

    b. Mixing cycles:

(1) Charge the mixing chamber with the rubber, lower the ram, and run the Banbury mixer for 1 min to masticate the rubber.

(2) Raise the ram and add all the zinc oxide, sulfur, stearic acid, accelerators, and antioxidants which had been previously blended. Then, add carbon black, sweep the orifice, lower the ram, and allow the batch to mix for 2 min.

(3) Stop the Banbury mixer, raise the ram, scrape, return all ingredients from ram to Banbury mixer, sweep, lower ram, and mix for 5 min before dumping the contents. Batch temperature should not exceed 220 degrees F during mixing.

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[2] Bergstrom, E., "Development of Wear-Resistant Elastomers for Track Pads," Weapons Command, Rock Island, IL, October 1972.

Table 1

SBR Formulations and Mixing Variables

Ingredient	15 SBR-1	15 SBR-2	15 SBR-3	15 SBR-4	15 SBR-5	15 SBR-6	15 SBR-7	15 SBR-8	15 SBR-9	15 SBR-10	15 SBR-11	15 SBR-12	15 SBR-13	15 SBR-14	15 SBR-15	15 SBR-16	15 SBR-17	15 SBR-26
Firestone SBR-1500	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Copolymer SBR-1500																		100.0
Zinc Oxide Kadox 15	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0			4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Zinc Oxide [illegible]									4.0									
Zinc Oxide AD - 520-86										4.6								
Stearic Acid	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
SAF Black N-110	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0	46.0		46.0	46.0
ISAF Black N-220																46.0		
Agerite Resin D	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Antozite 2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Sulfur - Rubbermakers	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0			2.0	1.5	5.0	2.0	2.0	2.0
Sulfur - Spider											2.0							
Sulfur - Polydor S												2.7						
Santocure	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5		1.0	1.5	1.5	1.5	1.5	1.5
Santocure - Polydox S												1.875						
Mixing Variables																		
Banbury Mixing																		
Batch Size Factor	1.	1.2	0.8	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
Mastication Time, Min	1	1	1	0	3	1	1	1	1	1	1	1	1	1	1	1	1	1
Final Mix Time, Min	7	7	7	7	7	5	15	7	7	7	7	7	7	7	7	7	5	7
Dump Temperature °F	<220	<220	<220	<220	<220	<220	<220	>220	<220	<220	<220	<220	<220	<220	<220	<220	<220	<220
Mill Mixing Number of Passes @ .032 Sn.	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		6
Number of Passes 0.080 Sn.																	3	
Number of Passes in Step 4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 2

Natural Rubber Formulations and Mixing Variables

Ingredient	15 NAT-1	15 NAT-2	15 NAT-3	15 NAT-4	15 NAT-5	15 NAT-6	15 NAT-7	15 NAT-8	15 NAT-9	15 NAT-10	15 NAT-11	15 NAT-12	15 NAT-13	15 NAT-14	15 NAT-15	15 NAT-16	15 NAT-17	15 NAT-18
Natural Rubber RSS-1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Zinc Oxide Kadox 15	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0			4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Zinc Oxide Akrochem									4.0									
Zinc Oxide PD 520-85										4.6								
Stearic Acid	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
SAF Black N-110	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0		45.0	
ISAF Black N-220 N-234																45.0		45.0
Agerite Resin D	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Antozite 2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3	3.0	3.0	3.0
Sulfur - Rubbermaids	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5			2.5	1.5	5	2.5	2.5	2.5
Sulfur - Spider											2.5							
Sulfur - Polydor S												3.3						
Santocure	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8		0.4	0.8	0.8	0.8	0.8	0.8
Santocure - Polydox S												1.						
Mixing Variables																		
Banbury Mixing																		
Batch Size Factor	1.	1.2	0.8	1.	1.	1.	1.	1.	1.	1.	1.			1.	1.	1.	1.	1.
Mastication Time, Min.	1	1	1	0	3	1	1	1	1	1	1	1	1	1	1	1	1	1
Final Mix Time, Min	2	2	2	2	2	2	2½	8	2	2	2	2	2	2	2	2	2½	2
Dump Temp, °F	<220	<220	<220	<220	<220	<220	<220	>220	<220	<220	<220	<220	<220	<220	<220	<220	<220	<220
Mill Mixing Number of Passes in Step 4	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	2	5
Number of Passes in Step 5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	2	5

2. Mill mixing procedure:

a. The mill shall be at room temperature when first adding the rubber from the Banbury mixer.

b. Pass the rubber through the mill at 0.020-in. opening once, then twice at 0.125-in. opening.

c. Pass the rolled batch endwise through the mill six times at a roll separation of .032 in.

d. Then, sheet off the compound at a setting of 0.085 to .100 in. after allowing the stock to band between the rolls for 30 s to obtain the effects of mill direction.

NATURAL RUBBER (NR) STANDARD MIXING PROCEDURE

The rubber is mixed in a Banbury mixer followed by a final mill mix as follows:

1. Banbury mixing procedure:

a. The Banbury mixer is run on low speed (77 c/m) with ambient cooling water turned on full.

b. Mixing cycles:

(1) Charge the mixing chamber with the rubber, lower the ram, and run the Banbury mixer for 1 min to break down the rubber.

(2) Raise the ram and add all the zinc oxide, stearic acid, antiozonants, and antioxidants which had been weighed and blended in a separate container. Then, add the carbon black, sweep the orifice, lower the ram, and mix for 2 min.

(3) Stop the Banbury mixer, raise the ram, scrape, return all ingredients from pan to Banbury mixer, sweep, lower ram, and run for another 4 min and dump the contents. Do not allow the rubber to exceed 220 degrees F during mixing.

2. Mill mixing procedure:

a. The mill shall be cold with ambient cooling water running and the nip set at 0.060 in.

b. Cool the rubber by passing rubber stock from Banbury mixer through mill three times without allowing to band on the rolls.

c. Band the stock, add accelerators and sulfur.

d. Pass the rolled batch endwise through the mill five times at a roll separation of .032 in.

e. Sheet off to desired thickness of 0.085 to 0.100 in. after allowing the stock to band between rolls for 30 s to obtain the effects of mill direction.

Variations in the standard mixing procedure, as noted in Tables 1 and 2, are detailed below. Each numbered procedure correlates with the last two digits of the compound number except for procedure 18 (15 SBR-26) where the polymer, rather than the black, is changed. Firestone had discontinued production of SBR-1500. Thus, the Copolymer Rubber Co. version of this elastomer was inserted in the program.

PROCESSING STUDY PROCEDURES

1. Control or standard mixing procedure is as detailed above. Three 1000-g batches were mixed for each formulation to provide sufficient cured compound for all testing and some degree of replication in both processing and testing.

2. Same as Procedure 1, except that the batch size shall be increased to 1200 g to simulate overloading the Banbury mixer.

3. Same as Procedure 1, except that the batch size shall be reduced to 800 g to simulate underloading the Banbury mixer.

4. Same as Procedure 1, except that the 1-min masticating or breakdown cycle in the Banbury mixer will be eliminated, and all the rubber and other ingredients will be added at the start.

5. Same as Procedure 1, except that the masticating or breakdown cycle will be extended 3 min.

6. Same as Procedure 1, except that the final time for the Banbury mixing cycle shall be reduced to 5 min for SBR and 2½ min for NR.

7. Same as Procedure 1, except that the final mix time for the Banbury mixing cycles shall be increased to 15 min for SBR and 8 min for NR.

8. Same as Procedure 1, except that the temperature of the mix shall be permitted to rise uncontrolled over 220 degrees F.

9. Same as Procedure 1, but use treated zinc oxide from Akrochem.

10. Same as Procedure 1, but use 85 percent zinc oxide dispersed in 15 percent SBR binder (Poly-Dispersion SZD-85).

11. Same as Procedure 1, but use Spider brand sulfur in lieu of rubber makers.

12. Same as Procedure 1, but use sulfur-polymer S (SS-75) and Santocure-Polydox S (SA-75) in SBR binder in lieu of rubber makers' sulfur and Santocure.

13. Same as Procedure 1, except reduce the amount of Santocure to 1 for SBR and 0.4 for NR but use same cure conditions, time, and temperature as for Procedure 1.

14. Same as Procedure 1, except reduce the amount of sulfur to 1.5 for both SBR and NR and keep the cure conditions the same as Procedure 1.

15. Same as Procedure 1, except increase sulfur content to 5 and maintain same cure conditions as Procedure 1.

16. Same as Procedure 1, except use ISAF (N220) black in lieu of N110.

17. Same as Procedure 1, except change mill mixing to:

a. For SBR:

(1) In step 3, pass the rubber endwise through mill three times at a roll separation of 0.032.

(2) In step 4, allow to band for 5 s.

b. For NR:

(1) In step 4, pass the rubber endwise through the mill twice at a roll separation of 0.032 in.

(2) In step 5, allow to band for 5 s.

18. For NR, same as Procedure 1, except use N234 black in lieu of N110. For SBR (compounds 15SBR-26) Copolymer's SBR 1500 is to be substituted, using Procedure 1.

b. Physical/Mechanical Testing. Table 3 gives all tests conducted on cured samples of all compounds prepared according to the processing study procedures. Current specifications, such as MIL-T-11891, for track shoe assemblies may still reference certain tests conducted according to Federal Test Method Standard 601. These have all been superseded by the ASTM methods in Table 3. As mentioned earlier, three batches were prepared and vulcanized for each compound. Thus, specimens used in each test contain duplicates, since several were taken from each batch to provide the required number and to give a representative cross-section relative to reproducibility of processing and test results. All compounds were cured under the same conditions of time and temperature as determined from rheometer curves for the standard compound No. 1, regardless of what alternatives might be interpreted from curves for compounds No. 2 through No. 18. Also, compression set buttons and flex specimens were cured 5 min longer than ASTM test slabs to compensate for increased thickness.

Three of the tests conducted—trouser tear, compressibility, and dispersion rating—have no direct ASTM or FTMS 601 equivalent. The typical tear test specimen is not designed to overcome two serious deficiencies—leg extension (modulus effect) during extension and development of knotty, irregular tears. The modified trouser tear,[3] using a specimen as shown in Figure 1, attempts to overcome these shortcomings through fabric reinforcement of the legs, thus providing a path of least resistance along the groove for tear propagation. The molded specimen groove dimensions in Figure 1 are slightly different than those cited in the reference to facilitate machining of the mold.

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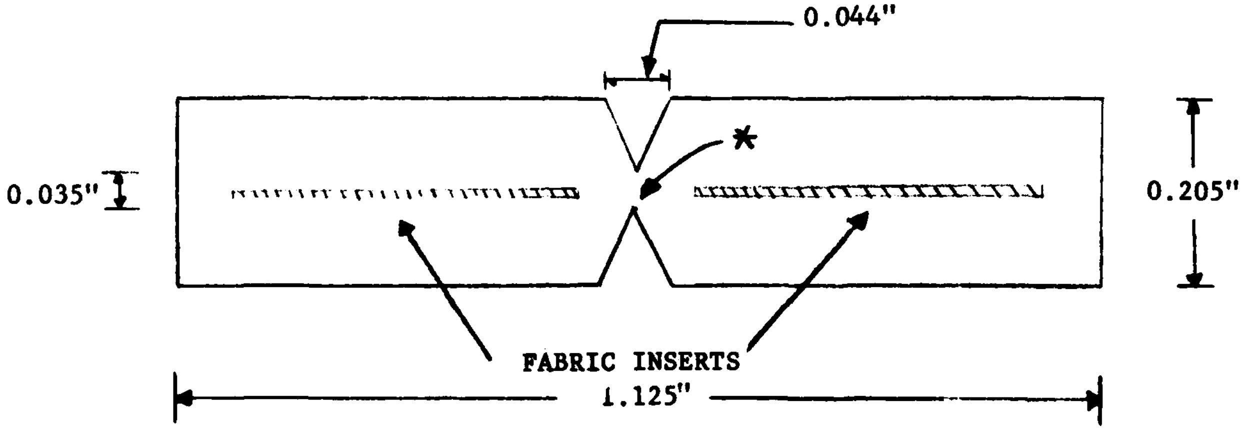
[3] Hewitt, N. L., "Compounding With Silica for Tear Strength and Low Heat Build-Up," PPG Industries, Pittsburgh, Pennsylvania, Rubber World June 1982.

Table 3. Properties and Test Methods

Test	Test Method
1. Mooney viscosity and curve	ASTM D1646
2. Rheometer data and curve	ASTM D2084
3. Properties of cured rubber run at room temperature:	
a. Specific gravity	ASTM D297, Para 15
b. Tensile strength	ASTM D412
c. Elongation	ASTM D412
d. 100 and 200 percent modulus	ASTM D412
e. Hardness, IRHD	ASTM D1415
f. Resilience, Bashore Rebound	ASTM D2632
g. Tear strength, Die C	ASTM D624
h. Trouser tear with fabric insert	
i. Abrasion, Taber	ASTM D3389
j. Abrasion, Pico	ASTM D2228
k. Compressibility	
l. Dispersion rating as observed under a 60-power microscope	
4. Properties on cured material run at 250 °F and 300 °F:	
a. Tear strength, Die C	ASTM D624
b. Trouser tear with fabric insert	
c. Compressibility	
5. Flex fatigue tests:	
a. DeMattia cut growth unaged & after aging 70 h at 212 °F	ASTM D813
b. Goodrich flex at 122 °F	ASTM D623, Method A using a 0.175 in. stroke and 141.6 lb/in.^{2} for determining heat build-up



* 15° on a side (30° included angle)

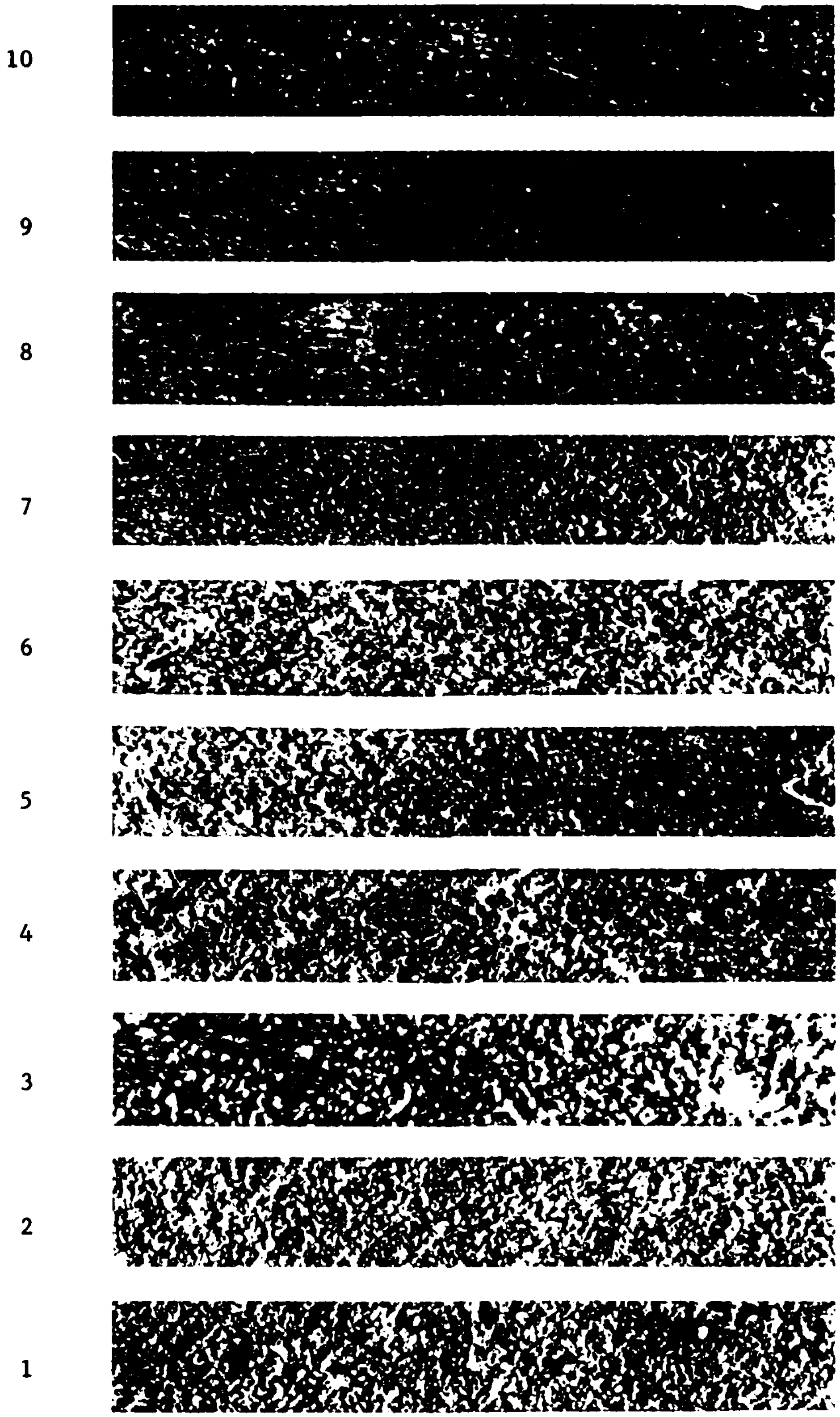
Figure 1. Modified Trouser Tear Specimen

Compressibility, unaged, after 4 and 70 h at 250 degrees F, and after a combined 4 h at both 250 degrees F and 300 degrees F, was determined using ASTM D395, Method B compression set buttons (1.129 in. in diameter and 0.5 in. thick). The buttons, for initial testing or after aging, were compressed 10, 20, and 40 percent, using an Instron 1123 Universal Testing Machine. Aged specimens were compressed within the attached chamber with all determinations run at a fixed crosshead speed of 0.2 in./min.

The effectiveness of compound mixing procedures which can have an ultimate effect upon the strength and dynamic properties of end items were ascertained visually by rating ingredient dispersion within the rubber matrix with the aid of a stereo microscope at 60X magnification. ASTM Method D2663 details a similar procedure. For this determination, a sharp ½-in. cut was made in a 1 x 2 x 0.070-in. section of the uncured compound. By grasping each portion of the cut sheet in one hand between the thumb and index finger and pulling apart rapidly in a direction opposite the line of the cut, an even torn surface suitable for viewing was produced. This torn area was observed and rated according to a scale of 1 to 10 (poor to excellent), as shown in Figure 2.

5. **Results.** Rheological data, obtained by the Monsanto rheometer and by Mooney Viscometer methods and numerical equivalents of visual dispersion ratings, are located in Table 4 for SBR compounds and in Table 5 for NR compounds. A representative Monsanto rheometer curve (Figure 3) is included here to clarify interpretation of tabular data. Original physical properties for all SBR compounds—tensile strength, 100 percent and 200 percent modulus, elongation, IRHD hardness, Bashore Rebound, and both Taber and Pico abrasion—are shown in Table 6. Similar results for the NR compounds are contained in Table 7. Die C and modified trouser tear properties, both original and after 10 min aging at 250 degrees F for each rubber type, are contained in Tables 8 and 9, respectively. Tables 10 and 11 summarize flex fatigue results, according to the DeMattia and Goodrich procedures. The DeMattia flex results also include rate of crack growth for specimens that had been aged 70 h at 100 degrees C. All Goodrich flex data (i.e., change in temperature after 25 min initial rate of temperature change, static and dynamic compression, and permanent set) are included. Compressibility properties of the SBR and NR compounds, unaged and after each of three heat-aging periods, are compiled in Tables 12 and 13, respectively.

Tables 14 and 15 contain a summarization of the effects of procedural and chemical modifications on various properties of the SBR and NR compounds, respectively, the relative degree of any increment or decrement being indicated by positive or negative signs. Figures 4 through 18 comprise a series of bar graphs included to highlight property trends or contrasts between or within the two polymer types used in the program. Photographs taken from the SEM, depicting dispersion of compounding ingredients, appear in Appendix A of this report.



NOTE: Based on system developed by Cabot Corporation (4)

Figure 2. Dispersion Rating

TABLE 4
RHEOLOGY AND DISPERSION PROPERTIES OF SBR RUBBER COMPOUNDS

	MONSANTO RHEOMETER							MOONEY VISCOMETER		
Compound ID	T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	ML1+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min	
15SBR 1A	4.0	6.5	12.5	7.5	37.0	11.8	3.5	64.3	10.1	7
15SBR 1B	4.0	6.3	12.0	7.5	37.0	12.5	3.7	63.0	10.1	8
15SBR 1C	4.0	6.3	12.5	8.0	37.5	11.8	3.5	62.8	9.7	8
Average	4.0	6.4	12.3	7.7	37.2	12.0	3.6	63.4	10.0	8
15SBR 2A	3.0	---	8.0	21.0	33.5	20.0	2.5	>200		2
15SBR 2B	2.8	---	9.3	20.3	37.5	15.4	2.7	>200		2
15SBR 2C	2.3	---	7.5	20.8	33.5	19.1	2.4	>200	(1)	2
Average	2.7	---	8.3	20.7	34.8	18.2	2.5	200		2
15SBR 3A	4.5	7.3	14.5	6.8	36.0	10.0	2.9	65.4	13.3	8
15SBR 3B	4.3	6.5	12.8	7.3	36.7	11.8	3.5	65.6	14.0	8
15SBR 3C	4.8	7.0	12.8	7.3	37.0	12.5	3.7	65.6	13.8	9
Average	4.5	6.9	13.4	7.1	36.6	11.4	3.4	65.5	13.7	8
15SBR 4A	3.5	5.8	11.5	7.3	36.5	12.5	3.7	66.3	10.3	8
15SBR-4B	3.5	5.8	11.5	7.3	36.5	12.5	3.7	65.4	11.4	8
15SBR-4C	3.5	5.8	11.5	7.3	36.5	12.5	3.7	66.1	10.8	8
Average	3.5	5.8	11.5	7.3	36.5	12.5	3.7	65.9	10.8	8
15SBR-5A	3.8	6.0	11.8	7.0	35.5	12.5	3.6	62.5	10.6	8
15SBR-5B	3.3	5.5	11.8	7.3	36.0	11.8	3.4	63.4	11.1	7
15SBR-5C	4.0	6.0	11.8	7.5	37.0	12.9	3.8	63.8	11.0	8
Average	3.7	5.8	11.8	7.3	36.2	12.4	3.6	63.2	10.9	8
15SBR-6A	4.0	6.5	12.3	7.3	36.0	12.1	3.5	64.5	11.8	6
15SBR-6B	4.0	6.0	11.8	7.3	36.0	12.9	3.7	65.2	11.4	7
15SBR-6C	4.0	6.0	11.8	7.3	36.0	12.9	3.7	65.1	12.0	7
Average	4.0	6.2	12.0	7.3	36.0	12.6	3.6	64.9	11.7	7

TABLE 4
RHEOLOGY AND DISPERSION PROPERTIES OF SBR RUBBER COMPOUNDS

	MONSANTO RHEOMETER							MOONEY VISCOMETER		
Compound ID	T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	ML1+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min	
15SBR-7A	2.8	4.3	11.0	11.8	36.0	12.1	2.9	140.9	2.8	7
15SBR-7B	2.0	3.0	10.0	15.0	36.0	12.5	2.6	>200	1.5	6 (2)
15SBR-7C	2.5	3.8	10.0	14.0	38.5	13.3	3.3	117.9	3.6	8
Average	2.4	3.7	10.3	13.6	36.8	12.6	2.9	129.4	2.6	7
15SBR-8A	3.3	6.0	12.0	7.3	36.5	11.4	3.3	67.9	9.3	7
15SBR-8B	4.0	6.0	12.0	7.1	36.0	12.5	3.6	65.7	12.1	7 (2)
15SBR-8C	3.5	6.0	12.0	7.3	36.3	11.8	3.4	67.1	11.6	7
Average	3.6	6.0	12.0	7.2	36.3	11.9	3.4	66.9	11.0	7
15SBR-9A	3.5	6.0	11.5	7.0	35.5	12.5	3.6	63.4	10.9	7
15SBR-9B	3.5	6.0	12.0	7.0	35.0	11.8	3.3	61.0	11.2	7
15SBR-9C	3.5	6.0	11.5	7.0	35.5	12.5	3.6	63.6	11.0	7
Average	3.5	6.0	11.7	7.0	35.3	12.3	3.5	62.7	11.0	7
15SBR-10A	4.0	6.5	12.5	7.0	35.5	11.8	3.4	62.2	11.9	8
15SBR-10B	4.0	6.8	12.5	7.0	35.0	11.8	3.3	62.3	12.3	8
15SBR-10C	4.0	6.5	12.5	7.0	35.3	11.8	3.3	62.9	11.4	9
Average	4.0	6.6	12.5	7.0	35.3	11.8	3.3	62.5	11.9	8
15SBR-11A	3.5	6.0	11.5	7.3	35.8	12.5	3.6	64.2	9.4	8
15SBR-11B	3.8	6.3	12.5	7.0	34.8	11.4	3.2	64.8	10.4	8
15SBR-11C	3.5	6.0	11.5	7.0	35.3	12.5	3.5	63.8	10.2	8
Average	3.6	6.1	11.8	7.1	35.3	12.1	3.4	64.3	10.0	8
15SBR-12A	4.0	6.5	13.0	7.0	34.5	11.1	3.1	65.4	9.5	8
15SBR-12B	4.0	6.5	13.0	7.0	34.5	11.1	3.1	65.0	9.8	8
15SBR-12C	4.5	7.0	13.5	7.0	34.0	11.1	3.0	65.6	9.2	8
Average	4.2	6.7	13.2	7.0	34.3	11.1	3.1	65.3	9.5	8

TABLE 4
RHEOLOGY AND DISPERSION PROPERTIES OF SBR RUBBER COMPOUNDS

	MONSANTO RHEOMETER							MOONEY VISCOMETER		
Compound ID	T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	ML1+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min	
15SBR-13A	4.0	7.5	17.5	7.0	32.8	7.4	1.9	65.0	12.8	8
15SBR-13B	4.0	7.5	16.8	7.5	32.5	7.8	2.0	66.9	12.7	8
15SBR-13C	4.0	7.5	16.8	7.0	32.5	7.8	2.0	65.0	14.1	8
Average	4.0	7.5	17.0	7.2	32.6	7.7	2.0	65.6	12.9	8
15SBR-14A	4.0	6.5	13.5	7.0	30.5	10.5	2.4	62.0	12.4	8
15SBR-14B	4.5	6.8	13.5	6.5	30.0	11.1	2.6	61.7	13.0	8
15SBR-14C	4.5	6.5	13.5	6.5	30.0	11.1	2.6	61.5	11.9	8
Average	4.3	6.6	13.5	6.7	30.2	10.9	2.5	61.7	12.4	8
15SBR-15A	2.5	5.5	14.0	7.0	52.5	8.7	4.0	63.8	6.0	8
15SBR-15B	2.8	6.3	14.0	7.0	49.5	8.9	3.8	64.2	6.0	8
15SBR-15C	2.8	6.0	14.0	7.0	50.0	8.9	3.8	63.2	6.2	8
Average	2.7	5.9	14.0	7.0	50.7	8.8	3.9	63.7	6.1	8
15SBR-16A	3.5	5.5	11.0	6.5	34.5	13.3	3.7	64.7	8.8	8
15SBR-16B	3.5	5.5	11.0	6.5	33.8	13.3	3.6	65.5	8.3	9
15SBR-16C	3.5	5.3	11.5	6.8	35.0	12.5	3.5	65.4	8.4	8
Average	3.5	5.4	11.2	6.6	34.4	13.0	3.6	65.2	8.5	8
15SBR-17A	4.5	7.0	14.0	6.3	33.8	10.5	2.9	60.9	12.8	7
15SBR-17B	4.3	6.8	13.0	6.3	34.0	11.4	3.2	62.6	10.9	7
15SBR-17C	4.5	7.0	13.5	6.3	34.5	11.1	3.1	62.9	11.9	7
Average	4.4	6.9	13.5	6.3	34.1	11.0	3.1	62.1	11.9	7
(3) 15SBR-26	4.3	7.0	11.3	6.8	30.0	11.1	2.6	63.8	11.5	9½

Notes:

(1) Test could not be run because viscosity of the compound was greater than 200.
(2) Knotty appearance
(3) All three batches of this material were mixed together, hence only one curve was ran.

TABLE 5
RHEOLOGY AND DISPERSION PROPERTIES OF NATURAL RUBBER COMPOUNDS

Compound ID	MONSANTO RHEOMETER T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	MOONEY VISCOMETER ML3+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min	
15NAT -1A	5.0	7.5	13.8	7.5	37.5	11.4	3.4	49.6	11.3	8
15NAT -1B	5.5	8.0	14.0	7.3	36.0	11.8	3.4	47.9	11.7	8
15NAT -1C	5.5	8.0	14.5	7.3	35.5	11.1	3.1	50.2	12.4	8
Average	5.3	7.8	14.1	7.4	36.3	11.4	3.3	49.2	11.8	8
15NAT -2A	5.0	6.8	10.0	8.0	38.0	20.0	6.0	50.1	10.8	7
15NAT -2B	4.5	6.3	9.5	7.0	35.5	20.0	5.7	49.6	10.0	7
15NAT -2C	4.5	6.3	9.8	12.8	37.0	19.1	4.6	48.1	10.1	7
Average	4.7	6.5	9.8	9.3	36.8	19.7	5.4	49.3	10.3	7
15NAT -3A	5.0	7.3	13.5	7.0	35.0	11.8	3.3	55.1	10.9	7
15NAT -3B	5.5	7.5	14.0	7.0	33.5	11.8	3.1	57.8	11.3	7
15NAT -3C	5.0	7.0	13.8	6.0	33.0	11.4	3.1	57.1	10.7	7
Average	5.2	7.3	13.8	6.7	33.8	11.7	3.2	56.7	11.0	7
15NAT -4A	5.0	7.0	13.0	7.5	34.5	12.5	3.4	64.6	10.8	8
15NAT -4B	5.5	8.0	14.5	7.5	34.0	11.1	2.9	66.7	11.1	8
15NAT -4C	5.0	7.0	13.0	7.5	34.5	12.5	3.4	66.4	10.9	8
Average	5.2	7.3	13.5	7.5	34.3	12.0	3.2	65.9	10.9	8
15NAT -5A	5.3	7.8	14.5	6.8	33.5	10.8	2.9	60.8	10.7	8
15NAT -5B	5.5	7.5	13.5	7.5	35.5	12.5	3.5	63.4	10.8	8 (A)
15NAT -5C	5.3	7.5	13.5	7.0	35.0	12.1	3.4	63.1	11.4	8 (B)
Average	5.4	7.6	13.8	7.1	34.7	11.8	3.3	62.4	11.0	8

NOTES:
(A)-Knotty
(B)-Voids

TABLE 5
RHEOLOGY AND DISPERSION PROPERTIES OF NATURAL RUBBER COMPOUNDS

	MONSANTO RHEOMETER							MOONEY VISCOMETER		
Compound ID	T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	ML3+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min	
15NAT -6A	5.3	7.3	14.0	8.5	35.5	11.4	3.1	73.2	9.6	8 (A)
15NAT -6B	5.3	6.8	13.5	8.5	35.5	12.1	3.3	67.5	9.4	8
15NAT -6C	5.3	7.3	13.5	8.0	34.0	12.1	3.2	72.5	10.1	8
Average	5.3	7.1	13.7	8.3	35.0	11.9	3.2	71.1	9.7	8
15NAT -7A	5.8	8.0	14.0	6.3	35.0	12.1	3.5	56.3	13.5	7 (A)
15NAT -7B	5.3	7.5	14.0	7.0	35.5	11.4	3.3	59.0	12.8	7 (B)
15NAT -7C	5.0	7.3	14.8	7.0	35.5	10.3	2.9	63.1	12.2	
Average	5.4	7.6	14.3	6.8	35.3	11.3	3.2	59.5	12.8	7
15NAT -8A	5.3	7.3	14.0	7.0	34.0	11.4	3.1	57.6	11.0	8 (A)
15NAT -8B	5.0	7.3	13.5	7.5	34.0	11.8	3.1	65.7	11.0	8 (A)
15NAT -8C	5.5	7.3	14.0	8.8	34.5	11.8	3.0	82.2	10.6	8 (A)
Average	5.3	7.3	13.8	7.8	34.2	11.7	3.1	68.5	10.9	8 (A)
15NAT -9A	5.8	8.5	14.0	7.0	35.8	10.8	3.1	68.3	14.0	8 (B)
15NAT -9B	5.8	8.0	14.0	6.8	35.3	11.1	3.2	64.8	14.2	9
15NAT -9C	5.5	7.8	14.8	7.8	35.3	10.8	3.0	67.9	13.8	9
Average	5.7	8.1	14.3	7.2	35.5	10.9	3.1	67.0	14.0	9
15NAT-10A	5.3	8.0	14.0	6.8	36.5	11.4	3.4	63.2	15.3	8 (B)
15NAT-10B	5.8	8.0	14.0	7.3	36.5	12.1	3.6	68.4	14.7	8 (B)
15NAT-10C	5.8	8.0	14.8	7.8	35.8	11.1	3.1	66.7	15.2	9
Average	5.6	8.0	14.3	7.3	36.3	11.5	3.4	66.1	15.1	8

NOTES
(A) Knotty
(B) Voids

TABLE 5
RHEOLOGY AND DISPERSION PROPERTIES OF NATURAL RUBBER COMPOUNDS

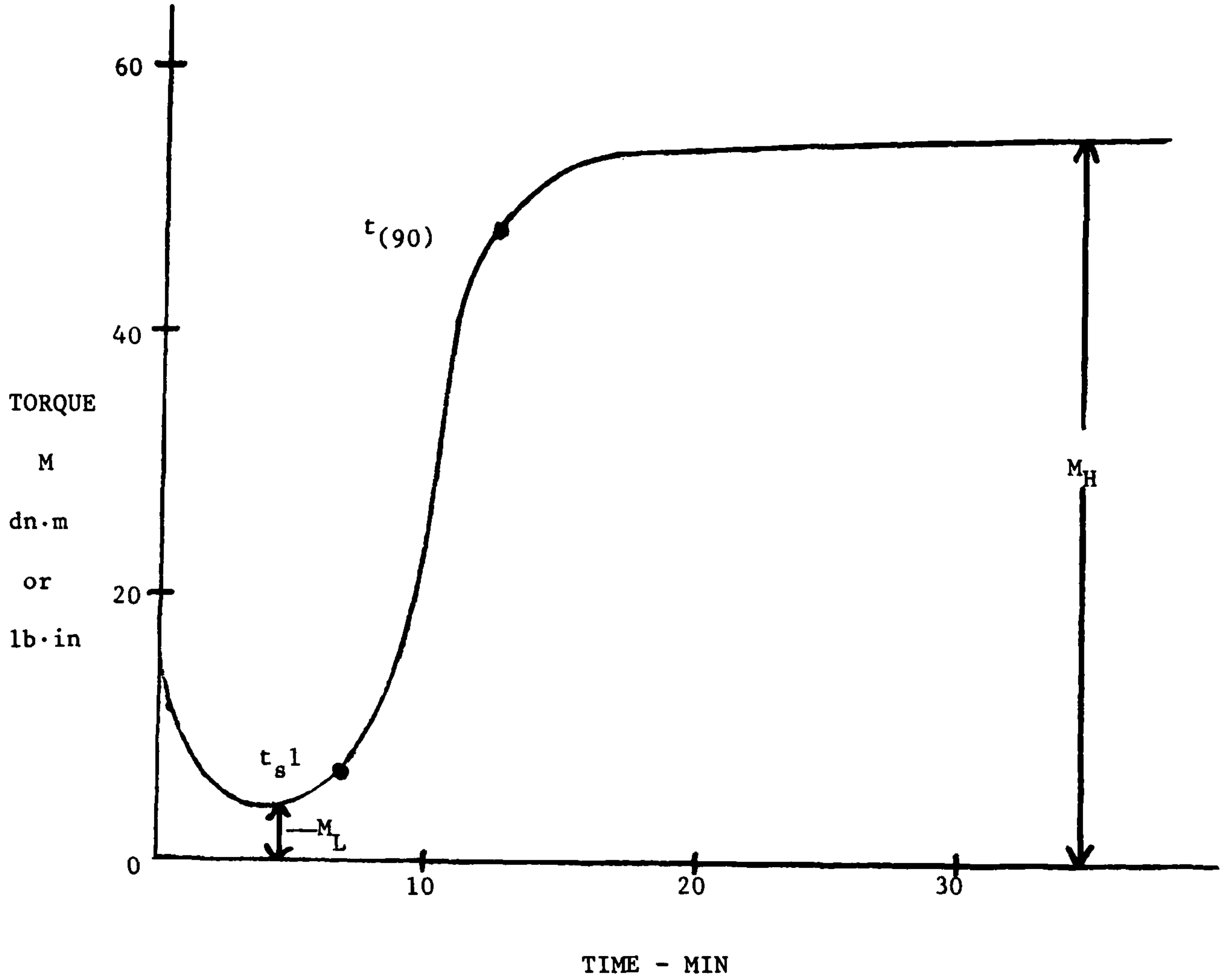
	MONSANTO RHEOMETER							MOONEY VISCOMETER		
Compound ID	T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	ML3+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min	
15NAT-11A	5.5	7.5	14.0	7.3	36.0	11.8	3.4	67.5	11.0	9
15NAT-11B	5.5	7.5	14.3	7.3	35.8	11.4	3.3	65.0	11.4	9
15NAT-11C	5.5	7.5	14.0	7.3	36.0	11.8	3.4	64.8	10.7	9
Average	5.5	7.5	14.1	7.3	35.9	11.7	3.4	65.8	11.0	9
15NAT-12A	6.3	9.3	16.0	6.0	35.5	10.3	3.0	61.0	15.9	9
15NAT-12B	6.3	9.0	15.5	6.0	34.5	10.8	3.1	65.8	15.6	9
15NAT-12C	6.3	8.8	15.3	6.3	35.0	11.1	3.2	66.4	15.6	9
Average	6.3	9.0	15.6	6.1	35.0	10.7	3.1	64.4	15.7	9
15NAT-13A	6.3	10.5	20.8	5.6	31.0	6.9	1.8	65.9	19.6	9
15NAT-13B	6.0	9.8	20.3	6.3	31.0	7.1	1.8	65.7	18.7	9
15NAT-13C	6.0	9.5	19.8	6.5	32.0	7.3	1.9	66.1	19.4	8
Average	6.1	9.9	20.3	6.1	31.3	7.1	1.8	65.9	19.2	9
15NAT-14A	7.0	9.5	15.0	6.0	29.5	12.5	2.9	67.8	19.7	9 (A)
15NAT-14B	7.0	9.3	14.5	6.0	29.5	13.3	3.1	66.0	19.5	9
15NAT-14C	6.8	9.0	14.0	6.3	29.8	13.8	3.2	70.6	18.5	9 (A)
Average	6.9	9.3	14.5	6.1	29.6	13.2	3.1	68.1	19.2	9 (A)
15NAT-15A	6.0	9.0	17.3	5.5	38.0	8.5	2.8	56.7	15.8	8 (A)
15NAT-15B	5.3	8.3	17.0	6.0	41.0	8.5	3.0	58.5	13.7	9
15NAT-15C	5.5	8.5	17.5	6.0	42.0	8.3	3.0	58.5	13.7	9
Average	5.6	8.6	17.3	5.8	40.3	8.4	2.9	57.9	14.4	9

NOTES:
(A) Knotty

TABLE 5
RHEOLOGY AND DISPERSION PROPERTIES OF NATURAL RUBBER COMPOUNDS

	MONSANTO RHEOMETER							MOONEY VISCOMETER			
Compound ID	T_S [1]	T_{50}	T_{90}	M_L	M_H	CRI	$\frac{M_H - M_L}{T_{90}-T_S}$ [1]	ML3+4 (212°F)	T_5 SCORCH 250°F	DISPERSION RATING	
	Min.	Min.	Min.	Lbf. In	Lbf. In				Min		
15NAT-16A	5.5	8.5	15.0	5.6	35.3	10.5	3.1	64.8	15.5	8	
15NAT-16B	6.0	9.0	15.5	6.0	35.0	10.5	3.1	65.7	15.2	9	
15NAT-16C	5.5	8.3	15.0	6.0	34.5	10.5	3.0	64.1	15.2	9	
Average	5.7	8.6	15.2	5.9	34.9	10.5	3.1	64.9	15.3	9	
15NAT-17A	6.0	8.5	15.5	6.0	35.5	10.5	3.1	63.6	17.0	8	
15NAT-17B	6.3	8.8	15.5	6.0	34.0	10.8	3.0	64.5	16.6	9	(A)
15NAT-17C	6.0	8.5	15.3	6.5	34.0	10.8	3.0	68.5	17.0	8	
Average	6.1	8.6	15.4	6.2	34.5	10.7	3.0	65.5	16.9	8	
15NAT-18A	5.5	8.3	15.5	5.5	35.0	10.0	3.0	58.5	13.6	8	(B)
15NAT-18B	5.5	8.0	15.0	5.5	35.3	10.5	3.1	59.6	13.5	8	
15NAT-18C	5.5	8.0	15.0	6.0	35.8	10.5	3.1	59.0	12.8	8	
Average	5.5	8.1	15.2	5.7	35.4	10.3	3.1	59.0	13.3	8	

NOTES:
(A) Knotty
(B) Voids



1. M_L - Minimum torque
2. M_H - Maximum or equilibrium torque
3. T_s1 - Time to 1 lbxIn., rise above M_L
4. T(90) - Time to 90% of maximum torque
5. T(50) - Time to 50% of maximum torque
6. CRI - Cure Rate Index $= \dfrac{100}{T(90)-T_s1}$

Figure 3. Typical Monsanto Rheometer Curve

TABLE 6

Original Physical Properties of SBR Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.²	lb/in.²	lb/in.²	%	Deg.	%	gm/ 1000 cycles	Rating
15SBR-1A	30/310	1.1325	3810	672	206	500	72	39	.1984	139
15SBR-1B	30/310	1.1328	3969	682	209	490	70	38	.1840	146
15SBR-1C	30/310	1.1303	3953	647	191	490	70	39	.1708	145
Average		1.1319	3911	667	202	493	71	39	.1844	143
15SBR-2A	30/310	1.1183	1990	615	185	340	70	38	.0607	173
15SBR-2B	30/310	1.1797	1955	970	250	270	71	38	.0635	182
15SBR-2C	30/310	1.1210	1685	795	195	280	71	41	.0922	182
Average		1.1397	1877	793	210	297	71	39	.0721	179
15SBR-3A	30/310	1.1223	4130	748	249	520	73	34	.1809	156
15SBR-3B	30/310	1.1188	4158	667	238	520	71	35	.1848	154
15SBR-3C	30/310	1.1214	3518	665	246	470	72	35	.1477	160
Average		1.1208	3935	693	244	503		35	.1711	157
15SBR-4A	30/310	1.1202	3480	692	222	460	70	36	.1684	141
15SBR-4B	30/310	1.1198	3985	780	221	490	71	36	.1631	141
15SBR-4C	30/310	1.1219	3358	735	233	440	71	36	.1609	149
Average		1.1206	3608	736	225	463	71	36	.1641	144
15SBR-5A	30/310	1.1160	4131	668	230	540	69	35	.1596	141
15SBR-5B	30/310	1.1187	3949	655	230	500	70	36	.2109	142
15SBR-5C	30/310	1.1202	3571	678	239	480	71	36	.1613	157
Average		1.1183	3884	667	233	507	70	36	.1773	147

TABLE 6

Original Physical Properties of SBR Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.²	lb/in.²	lb/in.²	%	Deg.	%	gm/ 1000 cycles	Rating
15SBR-6A	30/310	1.1171	3052	645	200	450	71	35	.1657	143
15SBR-6B	30/310	1.1198	3439	640	191	450	72	35	.1222	134
15SBR-6C	30/310	1.1172	3637	658	219	460	72	35	.1454	147
Average		1.1180	3376	647	203	453	72	35	.1444	141
15SBR-7A	30/310	1.1190	2956	756	221	380	71	38	.1241	170
15SBR-7B	30/310	1.1202	2736	1032	274	310	73	38	.1271	172
15SBR-7C	30/310	1.1206	4250	1006	281	420	72	38	.1384	168
Average		1.1199	3314	931	259	370	72	38	.1298	170
15SBR-8A	30/310	1.1195	4103	811	266	490	73	36	.0900	147
15SBR-8B	30/310	1.1202	3754	726	267	480	72	36	.1015	137
15SBR-8C	30/310	1.1196	4031	688	243	480	72	36	.1088	153
Average		1.1198	3962	741	253	483	72	36	.1001	146
15SBR-9A	30/310	1.1221	3451	712	233	460	70	37	.1437	141
15SBR-9B	30/310	1.1212	3412	779	218	455	70	36	.1577	129
15SBR-9C	30/310	1.1215	4026	647	198	500	71	37	.1394	133
Average		1.1216	3629	712	216	471	70	37	.1499	134
15SBR-10A	30/310	1.1203	3966	603	185	490	71	37	.1598	132
15SBR-10B	30/310	1.1280	3543	650	202	480	72	37	.1658	150
15SBR-10C	30/310	1.1198	3699	640	198	480	71	37	.1600	134
Average		1.1193	3736	631	195	483	71	37	.1618	139

TABLE 6

Original Physical Properties of SBR Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	%	Deg.	%	gm/ 1000 cycles	Rating
15SBR-11A	30/310	1.1125	3635	717	224	470	73	37	.1085	132
15SBR-11B	30/310	1.1200	3703	739	231	480	72	37	.0895	135
15SBR-11C	30/310	1.1206	3333	726	238	450	72	37	.0998	126
Average		1.1177	3557	728	231	467	72	37	.0993	131
15SBR-12A	30/310	1.1187	3510	639	195	480	70	35	.1605	124
15SBR-12B	30/310	1.1175	2993	592	146	430	70	35	.1702	126
15SBR-12C	30/310	1.1155	3597	673	198	490	71	35	.1650	120
Average		1.1172	3367	635	179	466	70	35	.1662	123
15SBR-13A	30/310	1.1197	3565	496	192	520	69	37	.1566	121
15SBR-13B	30/310	1.1205	3664	539	200	530	70	38	.1390	150
15SBR-13C	30/310	1.1209	3511	592	206	510	70	38	.1380	125
Average		1.1204	3580	542	199	520	70	38	.0946	132
15SBR-14A	30/310	1.1250	3795	425	137	580	66	37	.0946	133
15SBR-14B	30/310	1.1219	3713	445	137	570	66	38	.0766	120
15SBR-14C	30/310	1.1235	3418	452	153	550	68	37	.1267	126
Average		1.1235	3642	440	142	566	67	37	.0993	126
15SBR-15A	30/310	1.1387	2521	1924	515	230	79	33	.0647	166
15SBR-15B	30/310	1.1389	2236	1853	507	200	78	35	.0885	192
15SBR-15C	30/310	1.1390	2737	1957	546	250	78	34	.0697	168
Average		1.1389	2498	1911	522	233	77	34	.0743	175

TABLE 6

Original Physical Properties of SBR Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Harness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.²	lb/in.²	lb/in.²	%	Deg.	%	gm/ 1000 cycles	Rating
15SBR-16A	30/310	1.1261	3591	803	209	460	69	39	.1567	134
15SBR-16B	30/310	1.1259	3392	798	266	440	70	39	.1630	130
15SBR-16C	30/310	1.1250	3213	822	260	430	70	40	.1179	122
Average		1.1257	3398	807	245	443	70	39	.1459	129
15SBR-17A	30/310	1.1240	3332	685	200	480	68	38	.1510	126
15SBR-17B	30/310	1.1245	3432	719	191	470	68	38	.1138	122
15SBR-17C	30/310	1.1254	3804	725	213	510	69	38	.1401	116
Average		1.1246	3523	709	201	486	68	38	.1350	121
(1) 15SBR-26	30/310	1.1210	3779	734	291	525	65	40	.0575	148

Notes:

(1) All three batches of compound 15 SBR-26 were mixed together to form one batch.

TABLE 7

Original Properties of Natural Rubber Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.²	lb/in.²	lb/in.²	%	Deg.	%	gm/ 1000 cycles	Rating
15NAT 1-A	20/300	1.1076	3751	732	233	500	71	45	.3169	136
15NAT 1-B	20/300	1.1096	4010	736	263	510	70	44	.3866	134
15NAT 1-C	20/300	1.1108	3850	670	240	500	71	43	.3517	132
Average		1.1093	3870	712	245	503	71	44	.3517	134
15NAT 2-A	20/300	1.0949	3617	792	231	450	71	45	.4025	161
15NAT 2-B	20/300	1.0912	3894	792	231	500	72	45	.4129	151
15NAT 2-C	20/300	1.0948	3725	883	288	480	72	45	.4030	155
Average		1.0936	3745	822	250	476	72	45	.4061	156
15NAT 3-A	20/300	1.0962	3767	817	216	490	70	47	.2187	133
15NAT 3-B	20/300	1.0966	3882	897	248	500	70	47	.2891	157
15NAT 3-C	20/300	1.0969	3699	817	209	490	68	46	.2602	141
Average		1.0966	3782	843	224	493	69	47	.2560	144
15NAT 4-A	20/300	1.0972	3666	780	247	490	69	44	.3247	133
15NAT 4-B	20/300	1.0940	3840	672	205	530	69	47	.2569	150
15NAT 4-C	20/300	1.0940	3679	817	270	470	69	47	.2934	141
Average		1.0951	3728	756	240	497	69	46	.2917	141
15NAT 5-A	20/300	1.0914	3861	693	198	520	67	46	.2132	149
15NAT 5-B	20/300	1.0947	3664	685	200	500	69	48	.2950	143
15NAT 5-C	20/300	1.0953	3684	672	206	500	70	46	.2804	148
Average		1.0938	3736	683	201	506	69	47	.2629	147

TABLE 7

Original Properties of Natural Rubber Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	%	Deg.	%	gm/ 1000 cycles	Rating
15NAT 6-A	20/300	1.0948	3667	653	205	500	68	47	.2708	124
15NAT 6-B	20/300	1.0927	3645	682	209	500	69	47	.2761	159
15NAT 6-C	20/300	1.0922	3908	749	243	530	70	48	.3073	140
Average		1.0932	3740	694	219	510	69	47	.2847	140
15NAT 7-A	20/300	1.0968	3315	813	275	490	71	45	.2796	142
15NAT 7-B	20/300	1.0963	3107	793	273	450	71	45	.2804	145
15NAT 7-C	20/300	1.0971	3138	791	266	450	71	44	.3113	155
Average		1.0967	3187	799	271	463	71	45	.2904	147
15NAT 8-A	20/300	1.0935	3760	743	209	500	64	47	.3010	135
15NAT 8-B	20/300	1.0929	3603	691	213	500	66	47	.3080	137
15NAT 8-C	20/300	1.0943	3373	730	245	500	70	47	.2693	146
Average		1.0936	3578	721	222	500	67	47	.2928	139
15NAT 9-A	20/300	1.0969	3168	819	256	460	71	45	.2558	157
15NAT 9-B	20/300	1.0961	3617	805	264	500	71	45	.2350	162
15NAT 9-C	20/300	1.0958	3366	845	260	470	71	45	.2781	162
Average		1.0962	3384	823	260	477	71	45	.2563	160
15NAT 10-A	20/300	1.0985	3789	870	256	520	71	45	.2382	149
15NAT 10-B	20/300	1.0961	3423	908	311	470	73	45	.2782	160
15NAT 10-C	20/300	1.0961	3584	922	307	510	70	45	.2530	160
Average		1.0969	3599	900	291	500	71	45	.2565	156

TABLE 7

Original Properties of Natural Rubber Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.²	lb/in.²	lb/in.²	%	Deg.	%	gm/ 1000 cycles	Rating
15NAT-11A	20/300	1.1109	3386	842	275	470	73	45	.2727	136
15NAT-11B	20/300	1.1094	3684	778	278	500	71	44	.2602	144
15NAT-11C	20/300	1.1104	3606	919	313	500	71	46	.2775	139
Average		1.1103	3559	846	289	490	72	45	.2701	139
15NAT-12A	20/300	1.0978	3857	732	267	500	72	46	.2899	149
15NAT-12B	20/300	1.0946	3551	779	264	470	70	46	.2890	151
15NAT-12C	20/300	1.0962	3763	864	314	500	71	46	.2850	153
Average		1.0962	3724	792	282	490	71	46	.2880	151
15NAT-13A	20/300	1.0971	3808	710	256	540	67	47	.1879	152
15NAT-13B	20/300	1.0967	3875	694	250	550	69	46	.2015	141
15NAT-13C	20/300	1.0967	3689	730	343	500	71	45	.2469	150
Average		1.0968	3791	711	283	530	69	46	.2121	147
15NAT-14A	20/300	1.1068	3359	620	165	510	67	47	.1763	146
15NAT-14B	20/300	1.1068	3424	570	134	540	66	47	.3336	169
15NAT-14C	20/300	1.1056	3219	629	184	490	68	46	.1954	154
Average		1.1064	3334	606	161	510	67	47	.2351	156
15NAT-15A	20/300	1.0980	3562	984	330	490	70	50	.5253	138
15NAT-15B	20/300	1.0966	3443	1082	390	440	74	49	.5072	134
15NAT-15C	20/300	1.0960	3442	1080	387	430	74	47	.4404	142
Average		1.0969	3482	1049	369	453	73	49	.4910	138

TABLE 7

Original Properties of Natural Rubber Compounds

Compound ID	Cure	Specific Gravity	Tensile	Mod 200%	Mod 100%	Elong	Hardness IRHD	Bashore Rebound	Abrasion Taber	Abrasion Pico
	Min/°F		lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	%	Deg.	%	gm/ 1000 cycles	Rating
15NAT-16A	20/300	1.0980	3650	865	264	450	70	47	.5010	141
15NAT-16B	20/300	1.0966	3456	954	320	440	71	47	.4437	132
15NAT-16C	20/300	1.0960	3321	824	290	430	69	47	.4719	128
Average		1.0969	3476	881	291	440	70	47	.4722	134
15NAT-17A	20/300	1.0980	3104	768	256	440	70	47	.4844	144
15NAT-17B	20/300	1.0963	3603	755	282	500	69	47	.4417	139
15NAT-17C	20/300	1.0958	3471	791	279	480	70	48	.4823	137
Average		1.0967	3393	771	272	473	70	47	.4695	140
15NAT-18A	20/300	1.0940	3969	911	324	500	70	47	.6330	138
15NAT-18B	20/300	1.0954	3604	732	233	490	72	46	.5206	143
15NAT-18C	20/300	1.0947	3861	952	297	490	71	47	.5084	140
Average		1.0947	3811	865	285	493	71	47	.5540	140

Table 8. Tear Strength Properties of SBR Compounds

Compound ID	Tear Strength (lb/in.) ASTM, Die C Unaged	ASTM, Die C 10 min at 250 °F	Trouser Unaged	Trouser 10 min at 250 °F
15SBR-1A	319	181	67	90
15SBR-1B	296	157	103	90
15SBR-1C	297	158	84	(1)
Average	304	165	85	90
15SBR-2A	247	125	89	23
15SBR-2B	291	76		17
15SBR-2C	176	89	79	12
Average	238	97	84	17
15SBR-3A	286	176	73	(1)
15SBR-3B	287	161	95	(1)
15SBR-3C	299	175	67	56
Average	291	171	78	56
15SBR-4A	316	145	68	51
15SBR-4B	338	145	68	60
15SBR-4C	346	127	62	43
Average	333	139	66	51
15SBR-5A	325	171	67	57
15SBR-5B	321	118	63	63
15SBR-5C	313	128	71	48
Average	320	139	67	56
15SBR-6A	368	158	74	52
15SBR-6B	323	187	89	40
15SBR-6C	349	160	78	37
Average	347	168	80	43
15SBR-7A	295	118	63	34
15SBR-7B	231	128	90	17
15SBR-7C	312	167	98	28
Average	279	138	84	26
15SBR-8A	339	157	88	66
15SBR-8B	321	164	74	52
15SBR-8C	335	162	90	62
Average	332	161	84	60

Table 8. Tear Strength Properties of SBR Compounds (continued)

Compound ID	Tear Strength (lb/in.) ASTM, Die C Unaged	ASTM, Die C 10 min at 250 °F	Trouser Unaged	Trouser 10 min at 250 °F
15SBR-9A	316	130	79	79
15SBR-9B	319	119	71	68
15SBR-9C	321	151	79	61
Average	319	133	76	69
15SBR-10A	340	142	66	47
15SBR-10B	330	147	66	46
15SBR-10C	340	159	83	89
Average	337	149	72	61
15SBR-11A	320	145	84	55
15SBR-11B	310	127	90	53
15SBR-11C	324	166	78	65
Average	318	146	84	58
15SBR-12A	337	145	97	43
15SBR-12B	324	154	67	48
15SBR-12C	330	154	80	66
Average	330	151	81	52
15SBR-13A	308	136	98	52
15SBR-13B	293	158	102	63
15SBR-13C	292	158	83	55
Average	298	151	94	57
15SBR-14A	325	151	129	55
15SBR-14B	303	147	123	58
15SBR-14C	317	153	119	61
Average	315	150	124	58
15SBR-15A	246	124	35	—
15SBR-15B	241	90	24	(2)
15SBR-15C	231	99	23	—
Average	239	104	27	—
15SBR-16A	239	159	64	62
15SBR-16B	341	160	60	53
15SBR-16C	300	144	76	85
Average	293	154	67	67

Table 8. Tear Strength Properties of SBR Compounds (continued)

Compound ID	Tear Strength (lb/in.) ASTM, Die C: Unaged	ASTM, Die C: 10 min at 250 °F	Trouser: Unaged	Trouser: 10 min at 250 °F
15SBR-17A	276	164	55	65
15SBR-17B	308	135	85	66
15SBR-17C	303	143	52	85
Average	296	147	64	72
15SBR-26 (3)	315	141	96	79

Note: (1) Sample tore apart while in jaws.
(2) Sample tore to the side and not along groove.
(3) All three batches of compound 15SBR-26 were mixed into one batch.

Table 9. Tear Strength Properties of NR Compounds

Compound ID	Tear Strength (lb/in.) ASTM, Die C Unaged	ASTM, Die C 10 min at 250 °F	Trouser Unaged	Trouser 10 min at 250 °F
15NAT-1A	576	290	174	222
15NAT-1B	520	302	128	270
15NAT-1C	690	295	138	156
Average	595	296	147	216
15NAT-2A	489	281	275	256
15NAT-2B	549	258	207	267
15NAT-2C	476	290	176	211
Average	505	276	219	245
15NAT-3A	624	327	201	169
15NAT-3B	632	331	211	253
15NAT-3C	654	309	160	257
Average	637	322	191	226
15NAT-4A	576	259	261	203
15NAT-4B	563	286	250	178
15NAT-4C	558	284	151	153
Average	566	276	221	178
15NAT-5A	504	350	162	185
15NAT-5B	575	361	114	184
15NAT-5C	618	276	237	180
Average	566	329	171	183
15NAT-6A	639	295	199	236
15NAT-6B	566	273	202	232
15NAT-6C	555	253	178	243
Average	587	274	193	237
15NAT-7A	490	297	228	216
15NAT-7B	481	265	156	215
15NAT-7C	602	289	198	206
Average	524	284	194	212
15NAT-8A	604	276	280	195
15NAT-8B	621	288	226	193
15NAT-8C	531	308	147	215
Average	585	291	218	201

Table 9. Tear Strength Properties of NR Compounds (continued)

Compound ID	Tear Strength (lb/in.) ASTM, Die C Unaged	ASTM, Die C 10 min at 250 °F	Trouser Unaged	Trouser 10 min at 250 °F
15NAT-9A	533	268	162	196
15NAT-9B	510	284	88	189
15NAT-9C	505	284	116	252
Average	516	279	122	212
15NAT-10A	551	282	266	251
15NAT-10B	502	274	227	201
15NAT-10C	484	286	177	174
Average	512	281	223	209
15NAT-11A	594	297	232	208
15NAT-11B	602	308	207	224
15NAT-11C	478	262	164	163
Average	558	289	201	198
15NAT-12A	536	313	151	211
15NAT-12B	460	273	264	223
15NAT-12C	542	280	171	214
Average	513	289	195	216
15NAT-13A	534	331	172	254
15NAT-13B	631	313	156	224
15NAT-13C	713	313	240	223
Average	626	319	189	234
15NAT-14A	628	293	243	308
15NAT-14B	706	351	261	381
15NAT-14C	703	273	184	268
Average	679	306	229	319
15NAT-15A	415	239	127	118
15NAT-15B	392	257	123	157
15NAT-15C	453	244	105	229
Average	420	247	118	168
15NAT-16A	452	284	216	135
15NAT-16B	461	255	165	232
15NAT-16C	429	217	213	184
Average	447	252	198	184

Table 9. Tear Strength Properties of NR Compounds (continued)

Compound ID	Tear Strength (lb/in.) ASTM, Die C Unaged	ASTM, Die C 10 min at 250 °F	Trouser Unaged	Trouser 10 min at 250 °F
15NAT-17A	473	307	187	196
15NAT-17B	558	255	182	159
15NAT-17C	543	288	173	267
Average	525	283	181	207
15NAT-18A	500	305	189	114
15NAT-18B	490	258	192	294
15NAT-18C	546	304	204	222
Average	512	289	195	210

TABLE 10
FLEX FATIGUE PROPERTIES OF SBR RUBBER COMPOUNDS

	DeMattia Flex, Crack Growth			Goodrich Flex—Conditioned at 50°C				
	Unaged, 6000 cycles		Aged 70 Hrs @ 100° C					
	Crack Length	Rate of Growth	Rate of Growth	Δ T after 25 minutes	Initial rate of TEMP CHANGE	STATIC COMPRESSION	DYNAMIC COMPRESSION	PERMANENT SET
	1/64 In.	Mils/Min.	Mils/Min.	°C	°C/min	%	%	%
15SBR-1A	39	30.5	217.4	33.5	6.4	15.8	7.4	2.9
15SBR-1B	18	14.1	272.7	32.0	6.4	17.5	8.3	2.8
15SBR-1C	43	33.6	230.8	32.5	6.3	16.2	7.5	2.6
Average	33	26.1	240.3	32.7	6.4	16.5	7.7	2.8
15SBR-2A	62	48.4	1000.0	28.5	6.0	16.6	9.8	2.5
15SBR-2B	> 64	50.0	1363.6	29.54	6.1	17.2	9.0	2.0
15SBR-2C	> 64	50.0	1000.0	31.5	6.7	14.6	6.1	1.5
Average	> 63	49.5	1121.2	29.8	6.3	16.1	8.3	2.0
15SBR-3A	59	46.1	545.5	32.5	6.5	15.7	9.0	2.2
15SBR-3B	> 64	50.0	652.2	34.5	5.7	17.7	9.9	2.5
15SBR-3C	> 64	50.0	545.5	34.5	6.7	17.3	9.3	.8
Average	> 64	48.7	581.1	33.8	6.3	16.9	9.4	1.8
15SBR-4A	52	40.6	652.2	34.5	7.2	17.0	9.3	2.3
15SBR-4B	60	46.9	600.0	34.5	7.0	16.4	8.5	2.0
15SBR-4C	49	38.3	600.0	33.0	6.4	16.4	7.8	2.2
Average	54	41.9	617.4	34.0	6.9	16.6	8.5	2.2
15SBR-5A	47	36.7	625.0	34.0	6.7	17.9	9.4	2.6
15SBR-5B	54	42.2	625.0	33.8	6.4	16.7	8.6	2.4
15SBR-5C	62	48.4	625.0	32.0	6.1	17.2	8.3	1.6
Average	54	42.4	625.0	33.3	6.4	17.3	8.8	2.2
15SBR-6A	57	44.5	605.0	34.0	6.6	17.7	9.2	2.3
15SBR-6B	53	41.4	615.2	33.5	6.2	17.1	8.3	2.0
15SBR-6C	61	47.7	625.0	35.5	6.2	16.5	8.2	1.9
Average	57	44.5	615.1	34.3	6.3	17.1	8.6	2.1

TABLE 10
FLEX FATIGUE PROPERTIES OF SBR RUBBER COMPOUNDS

	DeMattia Flex, Crack Growth			Goodrich Flex-Conditioned at 50°C				
	Unaged, 6000 cycles		Aged 70 Hrs @ 100° C	Δ T after 25 minutes	Initial rate of TEMP CHANGE	STATIC COMPRESSION	DYNAMIC COMPRESSION	PERMANENT SET
	Crack Length	Rate of Growth	Rate of Growth					
	1/64 In.	Mils/Min.	Mils/Min.	°C	°C/min	%	%	%
15SBR-7A	> 64	50.0	625	32.5	5.4	15.5	7.4	1.4
15SBR-7B	> 64	50.0	625	32.5	6.1	16.0	6.9	.8
15SBR-7C	> 64	50.0	625	34.5	6.3	16.5	7.7	0
Average	> 64	50.0	625	33.2	5.9	16.0	7.3	.7
15SBR-8A	51	39.8	625	33.5	6.2	16.3	7.8	2.0
15SBR-8B	62	48.4	625	34.5	6.7	16.7	8.4	2.2
15SBR-8C	53	41.4	625	33.7	6.5	17.0	8.7	2.6
Average	55	43.2	625	33.9	6.5	16.7	8.3	2.3
15SBR-9A	46	35.9	414.1	33.0	6.5	16.5	8.5	1.7
15SBR-9B	41	32.0	445.3	33.5	6.5	18.4	9.9	2.1
15SBR-9C	45	35.2	437.5	34.5	6.9	17.4	9.4	2.1
Average	44	34.4	432.3	33.7	6.6	17.4	9.3	2.0
15SBR-10A	49	38.3	484.4	34.0	5.8	17.4	8.3	2.6
15SBR-10B	43	33.6	359.4	35.0	6.1	18.0	9.4	3.2
15SBR-10C	44	34.4	437.5	34.5	6.0	17.7	8.9	2.9
Average	45	35.4	427.1	34.5	6.0	17.7	8.9	2.9
15SBR-11A	47	36.7	414.1	32.0	5.4	16.3	7.8	2.5
15SBR-11B	41	32.0	398.4	33.5	5.7	16.6	9.3	2.4
15SBR-11C	42	32.8	429.7	34.0	5.8	18.1	9.6	2.6
Average	43	33.8	414.1	33.2	5.6	17.0	8.9	2.5
15SBR-12A	38	29.7	414.1	35.2	6.4	19.1	9.8	1.6
15SBR-12B	40	31.3	500.0	33.0	5.9	17.5	9.6	2.4
15SBR-12C	18	14.1	375.0	33.0	6.2	18.3	9.8	2.2
Average	32	25.0	429.7	33.7	6.2	18.3	9.7	2.1

TABLE 10
FLEX FATIGUE PROPERTIES OF SBR RUBBER COMPOUNDS

	DeMattia Flex, Crack Growth			Goodrich Flex-Conditioned at 50°C				
	Unaged, 6000 cycles		Aged 70 Hrs @ 100° C	Δ T after 25 minutes	Initial rate of TEMP CHANGE	STATIC COMPRESSION	DYNAMIC COMPRESSION	PERMANENT SET
	Crack Length	Rate of Growth	Rate of Growth					
	1/64 In.	Mils/Min.	Mils/Min.	°C	°C/min	%	%	%
15SBR-13A	24	18.8	250.0	37.0	6.7	17.9	11.0	6.4
15SBR-13B	28	21.9	250.0	36.5	6.9	17.7	10.8	4.5
15SBR-13C	26	20.3	240.0	35.0	6.9	17.5	12.3	4.3
Average	26	20.3	247.0	36.2	6.8	17.7	11.4	5.1
15SBR-14A	19	14.8	44.5	39.0	6.2	19.3	12.8	3.8
15SBR-14B	22	17.2	37.5	38.5	7.1	18.8	14.4	3.7
15SBR-14C	10	7.81	23.4	38.0	7.3	21.1	14.9	3.8
Average	17	13.3	35.1	38.5	6.9	19.7	14.0	3.8
15SBR-15A	> 64	> 50	41.4	29.0	5.4	10.4	1.8	1.1
15SBR-15B	> 64	> 50	40.6	25.0	4.4	10.0	1.6	1.3
15SBR-15C	> 64	> 50	39.8	27.0	5.6	9.6	.9	1.4
Average	> 64	> 50	40.6	27.0	5.1	10.0	1.4	1.3
15SBR-16A	45	35.2	400.0	31.5	5.0	16.2	7.4	1.5
15SBR-16B	45	35.2	400.0	30.5	5.3	15.9	7.1	1.4
15SBR-16C	43	33.6	400.0	32.0	5.9	15.5	7.2	1.7
Average	44	34.7	400.0	31.3	5.4	15.9	7.2	1.5
15SBR-17A	30	23.4	400.0	33.5	6.3	17.5	8.9	2.2
15SBR-17B	41	32.0	375.0	34.5	5.7	17.1	9.6	2.4
15SBR-17C	41	32.0	333.0	31.5	6.6	17.0	8.9	2.5
Average	37	29.1	369.0	33.2	6.2	17.2	9.1	2.4
15SBR-26A	32	24.7	259.0	37.7	7.2	19.3	12.3	2.6

Notes:

(1) All three batches of compound 15SBR-26 were mixed together to form one batch.

TABLE 11
FLEX FATIGUE OF NATURAL RUBBER COMPOUNDS

	DeMattia Flex, Crack Growth			Goodrich Flex-Conditioned at 50°C				
	Unaged, 6000 cycles		Aged 70 Hrs @ 100° C	Δ T after 25 minutes	Initial rate of TEMP CHANGE	STATIC COMPRESSION	DYNAMIC COMPRESSION	PERMANENT SET
	Crack Length	Rate of Growth	Rate of Growth					
	1/64 In.	Mils/Min.	Mils/Min.	°C	°C/min	%	%	%
15NAT-1A	24	18.8	21.1	22.0	3.9	17.2	13.0	3.2
15NAT-1B	23	18.0	23.4	24.0	3.7	18.3	12.9	3.3
15NAT-1C	24	18.8	28.1	26.0	4.2	17.7	12.7	3.0
Average	24	18.5	24.2	24.0	3.9	17.7	12.9	3.2
15NAT-2A	23	18.0	25.8	22.0	3.7	16.0	9.8	2.4
15NAT-2B	21	16.4	23.4	21.0	3.7	16.4	10.1	3.2
15NAT-2C	23	18.0	27.3	25.5	4.0	16.1	10.1	3.3
Average	22	17.5	25.5	22.8	3.8	16.2	10.0	3.0
15NAT-3A	21	16.4	25.0	20.5	3.2	17.2	10.8	3.3
15NAT-3B	22	17.2	21.1	21.3	3.6	17.3	10.8	2.7
15NAT-3C	22	17.2	23.4	22.0	3.8	16.7	11.1	3.4
Average	22	16.9	23.2	21.3	3.5	17.1	10.9	3.1
15NAT-4A	20	15.6	23.4	20.3	3.4	17.8	11.0	3.6
15NAT-4B	19	14.8	21.9	23.0	2.9	17.7	10.5	2.2
15NAT-4C	10	7.8	28.1	21.0	3.9	17.7	11.1	2.7
Average	16	12.7	24.5	21.4	3.4	17.7	10.9	2.8
15NAT-5A	20	15.6	23.4	20.5	3.3	17.4	10.6	3.0
15NAT-5B	23	18.0	24.2	21.5	3.9	17.5	11.0	3.3
15NAT-5C	23	18.0	21.9	22.0	3.8	17.3	11.0	3.2
Average	22	17.2	23.2	21.3	3.7	17.4	10.9	3.2
15NAT-6A	25	19.5	22.7	21.0	3.6	14.9	10.4	2.8
15NAT-6B	22	17.2	22.7	21.5	3.7	16.4	11.0	3.1
15NAT-6C	21	16.4	23.4	21.3	3.8	16.6	10.5	2.7
Average	23	17.7	22.9	21.3	3.7	16.0	10.6	2.9

TABLE 11
FLEX FATIGUE OF NATURAL RUBBER COMPOUNDS

	DeMattia Flex, Crack Growth			Goodrich Flex—Conditioned at 50°C				
	Unaged, 6000 cycles		Aged 70 Hrs @ 100° C	ΔT after 25 minutes	Initial rate of TEMP CHANGE	STATIC COMPRESSION	DYNAMIC COMPRESSION	PERMANENT SET
	Crack Length	Rate of Growth	Rate of Growth					
	1/64 In.	Mils/Min.	Mils/Min.	°C	°C/min	%	%	%
15NAT-7A	18	14.1	22.7	21.8	3.8	15.5	11.3	3.1
15NAT-7B	22	17.2	27.3	22.3	3.8	16.1	11.1	2.5
15NAT-7C	21	16.4	21.1	23.0	4.2	18.0	11.2	3.5
Average	20	15.9	23.7	22.4	3.9	16.5	11.2	3.0
15NAT-8A	21	16.4	22.7	22.5	3.8	18.5	12.7	3.5
15NAT-8B	15	11.7	19.5	20.0	3.2	17.9	12.7	3.4
15NAT-8C	22	17.2	21.9	20.5	3.7	17.5	11.3	2.4
Average	19	15.1	21.4	21.0	3.6	18.0	12.2	3.1
15NAT-9A	21	16.4	25.0	21.5	3.7	16.6	10.8	3.0
15NAT-9B	22	17.2	19.5	23.0	3.6	16.7	10.9	2.8
15NAT-9C	16	12.5	21.1	22.5	3.9	16.8	11.0	3.2
Average	20	15.4	21.9	22.3	3.7	16.7	10.9	3.0
15NAT-10A	24	18.8	25.0	22.5	4.1	16.9	11.0	2.3
15NAT-10B	23	18.0	26.6	22.3	4.3	16.4	10.8	2.8
15NAT-10C	20	15.6	25.0	22.0	4.3	16.1	11.2	2.7
Average	22	17.5	25.5	22.3	4.2	16.5	11.0	2.6
15NAT-11A	26	20.3	29.7	21.5	3.6	16.2	10.4	3.2
15NAT-11B	25	19.5	25.8	23.0	3.8	15.9	10.9	3.9
15NAT-11C	21	16.4	25.0	26.0	4.6	15.7	11.1	3.4
Average	24	18.7	26.8	23.5	4.0	15.9	10.8	3.5
15NAT-12A	22	17.2	25.0	19.0	3.6	16.2	10.0	1.9
15NAT-12B	22	17.2	23.4	19.8	3.4	16.1	10.1	2.1
15NAT-12C	22	17.2	25.8	20.3	3.5	16.5	10.1	2.5
Average	22	17.2	24.7	19.7	3.5	16.3	10.1	2.2

TABLE 11
FLEX FATIGUE OF NATURAL RUBBER COMPOUNDS

	DeMattia Flex, Crack Growth			Goodrich Flex-Conditioned at 50°C				
	Unaged, 6000 cycles		Aged 70 Hrs @ 100° C	Δ T after 25 minutes	Initial rate of TEMP CHANGE	STATIC COMPRESSION	DYNAMIC COMPRESSION	PERMANENT SET
	Crack Length	Rate of Growth	Rate of Growth					
	1/64 In.	Mils/Min.	Mils/Min.	°C	°C/min	%	%	%
15NAT-13A	19.0	14.8	15.6	21.0	3.8	18.7	12.9	3.3
15NAT-13B	21.0	16.4	9.4	22.5	4.1	18.9	13.8	3.3
15NAT-13C	15.0	11.7	11.7	22.0	3.9	18.6	13.9	5.0
Average	18.0	14.3	12.2	21.8	3.9	18.7	13.5	3.9
15NAT-14A	12.5	16.0	12.5	25.0	4.3	21.8	15.4	2.7
15NAT-14B	14.8	19.0	23.4	25.0	4.4	21.8	16.5	2.7
15NAT-14C	14.8	19.0	13.3	26.0	4.5	21.4	15.5	3.0
Average	14.0	18.0	16.4	25.3	4.4	21.7	15.8	2.8
15NAT-15A	14.8	19.0	317.8	19.5	3.3	15.6	8.7	2.2
15NAT-15B	17.2	22.0	243.9	18.0	3.3	14.9	7.8	2.2
15NAT-15C	17.2	22.0	317.8	18.0	2.9	14.6	7.6	2.1
Average	16.4	21.0	293.2	18.5	3.2	15.0	8.0	2.2
15NAT-16A	18.0	23.0	23.4	19.5	3.3	17.9	9.9	1.3
15NAT-16B	19.5	25.0	25.0	20.5	3.9	18.5	11.2	1.0
15NAT-16C	13.3	17.0	22.7	21.0	3.5	18.2	10.8	1.6
Average	16.9	22.0	23.7	20.3	3.6	18.2	10.6	1.3
15NAT-17A	15.6	20.0	25.0	22.0	3.5	17.4	10.5	1.5
15NAT-17B	17.2	22.0	25.0	20.0	3.8	19.2	11.6	2.1
15NAT-17C	16.4	21.0	29.7	22.0	4.0	19.1	11.9	2.1
Average	16.4	21.0	26.6	21.3	3.8	18.6	11.3	1.9
15NAT-18A	17.2	22.0	23.4	21.0	3.4	17.5	10.7	1.9
15NAT-18B	19.5	25.0	18.8	22.5	3.9	18.1	10.9	2.4
15NAT-18C	18.0	23.0	20.3	23.0	4.2	17.2	10.4	2.7
Average	18.2	23.0	20.8	22.2	3.8	17.6	10.7	2.3

TABLE 12
COMPRESSIBILITY PROPERTIES of SBR COMPOUNDS

	UNAGED			AGED								
	COMPRESSED			AFTER 4 Hrs @ 250°F, COMPRESSED			AFTER 70 Hrs @ 250°F, COMPRESSED			AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED		
Compound	10%	20%	40%	10%	20%	40%	10%	20%	40%	10%	20%	40%
ID	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}
15SBR-1A	140	268	685	121	247	537	161	309	718	114	225	532
15SBR-1B	138	269	719	106	211	487	143	280	659	101	207	492
15SBR-1C	143	279	753	106	211	482	130	273	651	102	210	497
Average	140	272	719	111	223	502	145	287	676	106	214	507
15SBR-2A	115	238	627	78	146	346	91	207	514	104	209	497
15SBR-2B	126	268	739	91	204	497	109	254	633	81	160	412
15SBR-2C	106	234	631	59	161	408	84	209	533	76	168	406
Average	116	247	666	76	170	417	95	223	560	87	179	438
15SBR-3A	102	231	619	104	213	504	140	281	657	111	215	508
15SBR-3B	143	272	732	99	210	505	123	265	632	63	166	422
15SBR-3C	141	269	715	92	205	500	141	284	671	102	213	508
Average	129	257	689	98	209	503	135	277	653	92	198	479
15SBR-4A	132	262	702	89	192	464	101	237	571	114	220	510
15SBR-4B	142	274	735	95	198	467	137	274	632	103	200	474
15SBR-4C	141	275	738	93	198	469	113	247	599	107	210	433
Average	138	270	725	92	196	467	117	253	601	108	210	472
15SBR-5A	133	255	671	86	190	464	121	247	577	110	213	495
15SBR-5B	118	240	628	93	199	476	110	231	560	108	214	485
15SBR-5C	134	261	699	80	179	444	143	280	650	97	199	475
Average	128	252	666	86	189	461	125	253	596	105	209	485

TABLE 12
COMPRESSIBILITY PROPERTIES of SBR COMPOUNDS

Compound ID	UNAGED COMPRESSED 10% lb/in.^{2}	UNAGED COMPRESSED 20% lb/in.^{2}	UNAGED COMPRESSED 40% lb/in.^{2}	AGED: AFTER 4 Hrs @ 250°F, COMPRESSED 10% lb/in.^{2}	AGED: AFTER 4 Hrs @ 250°F, COMPRESSED 20% lb/in.^{2}	AGED: AFTER 4 Hrs @ 250°F, COMPRESSED 40% lb/in.^{2}	AGED: AFTER 70 Hrs @ 250°F, COMPRESSED 10% lb/in.^{2}	AGED: AFTER 70 Hrs @ 250°F, COMPRESSED 20% lb/in.^{2}	AGED: AFTER 70 Hrs @ 250°F, COMPRESSED 40% lb/in.^{2}	AGED: AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED 10% lb/in.^{2}	AGED: AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED 20% lb/in.^{2}	AGED: AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED 40% lb/in.^{2}
15SBR-6A	134	257	699	82	183	453	147	277	667	92	192	463
15SBR-6B	142	270	726	78	181	448	126	258	618	95	196	470
15SBR-6C	145	271	725	88	195	475	142	276	655	122	230	534
Average	140	266	717	83	186	459	138	270	647	103	206	489
15SBR-7A	117	254	694	85	194	477	147	292	699	101	209	497
15SBR-7B	131	258	716	73	183	464	136	281	669	111	221	518
15SBR-7C	142	281	768	69	175	438	164	313	763	114	224	515
Average	130	264	726	76	184	460	149	295	710	109	218	510
15SBR-8A	143	270	723	115	224	530	135	273	647	108	217	507
15SBR-8B	143	271	728	108	218	513	154	293	677	107	216	503
15SBR-8C	146	279	749	96	204	492	153	293	683	100	210	501
Average	144	273	733	106	215	512	147	286	669	105	214	504
15SBR-9A	135	264	711	96	198	469	143	280	656	111	213	467
15SBR-9B	127	249	658	93	190	438	124	255	596	108	207	474
15SBR-9C	130	255	676	94	198	468	136	264	615	109	213	497
Average	131	256	682	94	195	458	134	266	622	109	211	479
15SBR-10A	135	257	673	87	198	468	136	268	624	105	210	488
15SBR-10B	133	255	682	83	186	454	121	242	581	103	207	481
15SBR-10C	135	261	708	108	213	501	122	244	582	117	217	516
Average	134	258	688	93	199	474	126	251	596	108	211	495

TABLE 12
COMPRESSIBILITY PROPERTIES of SBR COMPOUNDS

Compound	UNAGED			AGED								
	COMPRESSED			AFTER 4 Hrs @ 250°F, COMPRESSED			AFTER 70 Hrs @ 250°F, COMPRESSED			AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED		
	10%	20%	40%	10%	20%	40%	10%	20%	40%	10%	20%	40%
ID	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}
15SBR-11A	136	270	732	83	191	467	134	272	652	122	232	525
15SBR-11B	132	257	692	87	190	457	139	276	644	110	212	489
15SBR-11C	133	259	694	109	214	503	153	291	678	119	224	504
Average	134	262	706	93	198	476	142	280	658	117	223	506
15SBR-12A	129	250	665	105	201	471	126	253	603	113	212	486
15SBR-12B	128	249	672	98	184	442	132	257	613	106	204	472
15SBR-12C	126	245	659	103	204	475	133	247	590	101	197	455
Average	128	248	665	102	196	463	130	252	602	107	204	471
15SBR-13A	116	223	593	82	175	416	119	236	562	103	201	469
15SBR-13B	118	229	609	103	201	472	114	231	552	104	201	452
15SBR-13C	125	243	658	86	178	422	118	246	586	103	195	448
Average	120	232	620	90	185	437	117	238	567	103	199	456
15SBR-14A	109	212	558	87	173	408	112	215	497	100	190	428
15SBR-14B	111	215	570	82	167	390	117	222	509	99	182	406
15SBR-14C	111	216	570	88	175	416	113	216	504	98	184	413
Average	110	214	566	86	172	405	114	218	503	99	185	416
15SBR-15A	206	426	1257	169	363	912	194	420	1115(1)	172	354	872
15SBR-15B	204	443	1287	146	332	853	221	449	1169(1)	184	356	873
15SBR-15C	201	416	1267	167	351	880	187	409	1083(1)	169	348	847
Average	204	428	1,270	161	349	882	201	426	1122(1)	175	353	864

Notes:

(1) Sample ruptured at sides during compression.

TABLE 12
COMPRESSIBILITY PROPERTIES of SBR COMPOUNDS

Compound ID	UNAGED			AGED								
	COMPRESSED			AFTER 4 Hrs @ 250°F, COMPRESSED			AFTER 70 Hrs @ 250°F, COMPRESSED			AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED		
	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}
15SBR-16A	134	270	754	90	204	497	129	265	637	81	186	455
15SBR-16B	133	264	732	89	194	471	116	247	622	104	207	484
15SBR-16C	130	276	755	94	201	486	145	269	649	112	219	509
Average	132	270	747	91	200	485	130	260	636	99	204	483
15SBR-17A	92	214	584	102	198	457	118	241	583	78	173	418
15SBR-17B	122	244	662	110	214	486	121	245	589	81	177	423
15SBR-17C	112	232	646	99	199	471	110	238	575	102	203	465
Average	109	230	631	104	204	471	116	241	582	87	184	435
(1) 15SBR-26	122	237	657	78	175	425	90	200	502	82	177	447

Notes: (1) All three batches of compound 15SBR-26 were mixed together to form one batch.

TABLE 13
COMPRESSIBILITY PROPERTIES of NATURAL RUBBER COMPOUNDS

Compound	UNAGED			AGED								
	COMPRESSED			AFTER 4 Hrs @ 250°F, COMPRESSED			AFTER 70 Hrs @ 250°F, COMPRESSED			AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED		
	10%	20%	40%	10%	20%	40%	10%	20%	40%	10%	20%	40%
ID	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}	lb/in.^{2}
15NAT-1A	136	258	697	83	167	388	108	190	439	78	140	317
15NAT-1B	134	255	698	90	175	398	97	172	409	70	131	299
15NAT-1C	147	272	736	93	175	390	107	187	438	69	128	293
Average	139	262	710	89	172	392	104	183	429	72	133	303
15NAT-2A	141	269	573	83	176	428	105	190	441	80	153	352
15NAT-2B	128	251	546	76	159	383	88	163	377	78	142	324
15NAT-2C	137	262	678	69	158	390	103	188	442	82	151	350
Average	135	261	599	76	164	400	99	180	420	80	149	342
15NAT-3A	123	239	644	64	137	334	94	171	415	61	117	273
15NAT-3B	123	237	631	76	152	360	94	172	416	65	121	285
15NAT-3C	124	241	630	65	138	349	104	183	446	68	124	292
Average	123	239	635	68	142	348	97	175	426	65	121	283
15NAT-4A	127	245	674	91	170	396	100	180	430	62	116	274
15NAT-4B	122	236	656	83	160	365	91	168	412	69	127	296
15NAT-4C	127	248	689	64	143	348	103	184	443	66	124	291
Average	125	243	673	79	158	370	98	177	428	66	122	287
15NAT-5A	117	228	632	80	156	364	95	168	410	64	117	274
15NAT-5B	129	249	690	91	172	389	82	160	380	63	119	282
15NAT-5C	126	246	675	80	158	369	88	166	389	60	115	271
Average	124	241	666	84	162	374	88	165	393	62	117	276
15NAT-6A	130	252	673	85	167	391	104	188	444	67	128	296
15NAT-6B	129	249	658	74	153	357	100	179	419	70	127	289
15NAT-6C	124	242	643	70	149	353	97	179	415	69	127	281
Average	128	248	658	76	156	367	100	182	426	69	127	289

TABLE 13
COMPRESSIBILITY PROPERTIES of NATURAL RUBBER COMPOUNDS

	UNAGED			AGED								
	COMPRESSED			AFTER 4 Hrs @ 250°F, COMPRESSED			AFTER 70 Hrs @ 250°F, COMPRESSED			AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED		
Compound	10%	20%	40%	10%	20%	40%	10%	20%	40%	10%	20%	40%
ID	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$	$lb/in.^2$
15NAT-7A	125	239	611	68	148	354	103	188	451	71	134	314
15NAT-7B	129	241	581	73	152	359	94	172	422	78	143	331
15NAT-7C	125	236	579	77	156	364	88	162	403	77	141	327
Average	126	239	590	73	152	359	95	174	425	75	139	324
15NAT-8A	122	240	659	71	150	357	98	174	425	65	121	279
15NAT-8B	122	242	679	77	157	371	88	165	404	71	128	295
15NAT-8C	129	255	720	70	153	364	89	167	402	60	118	285
Average	124	246	686	73	153	364	92	169	410	65	122	286
15NAT-9A	132	254	678	49	134	328	93	178	427	78	143	329
15NAT-9B	130	249	638	46	131	322	97	182	433	84	151	344
15NAT-9C	133	251	618	63	150	357	95	180	432	77	146	340
Average	132	251	645	53	138	336	95	180	431	80	147	338
15NAT-10A	127	243	612	92	171	379	102	189	445	80	142	327
15NAT-10B	130	246	621	60	143	334	98	188	453	82	145	328
15NAT-10C	121	233	608	99	184	411	99	182	451	83	151	343
Average	126	241	614	84	166	375	100	186	450	82	146	333
15NAT-11A	160	295	840	100	188	421	95	190	455	90	159	356
15NAT-11B	170	305	880	63	146	350	90	170	430	84	152	344
15NAT-11C	155	295	850	75	145	326	90	170	430	69	123	280
Average	162	298	857	79	160	366	92	177	438	81	145	327
15NAT-12A	140	270	780	80	170	420	75	160	400	60	130	325
15NAT-12B	130	260	750	70	155	390	70	150	385	60	125	320
15NAT-12C	150	285	815	77	170	400	80	160	400	65	130	330
Average	140	272	782	75	165	403	75	157	395	62	128	325

TABLE 13
COMPRESSIBILITY PROPERTIES of NATURAL RUBBER COMPOUNDS

	UNAGED			AGED								
	COMPRESSED			AFTER 4 Hrs @ 250°F, COMPRESSED			AFTER 70 Hrs @ 250°F, COMPRESSED			AFTER 4 Hrs @ 250°F + 4 Hrs AT 300°F, COMPRESSED		
Compound ID	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}	10% lb/in.^{2}	20% lb/in.^{2}	40% lb/in.^{2}
15NAT-13A	130	250	700	70	145	420	75	145	355	50	110	280
15NAT-13B	130	242	680	65	140	390	70	140	340	60	115	285
15NAT-13C	132	255	730	65	140	400	70	150	350	60	110	280
Average	131	249	703	67	142	343	72	145	348	57	112	282
15NAT-14A	125	235	670	65	140	350	60	130	320	65	130	320
15NAT-14B	123	235	650	60	130	320	60	130	310	70	130	320
15NAT-14C	130	240	655	60	135	335	60	130	320	65	130	320
Average	126	237	658	62	135	335	60	130	317	67	130	320
15NAT-15A	148	295	880	80	185	455	95	190	490	80	150	365
15NAT-15B	163	329	990	100	215	525	100	205	530	75	155	380
15NAT-15C	173	347	1030	100	220	520	105	220	550	70	150	375
Average	161	324	967	93	207	500	100	205	523	75	152	373
15NAT-16A	148	290	870	80	180	445	90	175	430	60	135	345
15NAT-16B	140	280	860	80	175	440	80	165	420	75	150	365
15NAT-16C	140	280	840	80	180	440	80	170	400	65	130	335
Average	143	283	857	80	178	442	83	170	417	65	138	348
15NAT-17A	140	270	790	80	170	420	80	160	395	60	130	335
15NAT-17B	132	260	760	70	160	400	80	155	385	60	125	315
15NAT-17C	132	270	790	70	160	400	85	160	400	65	130	330
Average	135	267	780	73	163	407	82	158	418	62	128	333
15NAT-18A	145	285	840	75	165	400	95	180	420	60	130	320
15NAT-18B	150	295	855	80	170	415	90	170	415	65	135	335
15NAT-18C	155	295	860	85	180	430	95	180	420	70	140	350
Average	150	292	852	80	172	415	93	177	418	65	135	335

Table 14

Effect of Processing and Compounding Variables on Properties-SBR

Property	15 SBR-1	15 SBR-2	15 SBR-3	15 SBR-4	15 SBR-5	15 SBR-6	15 SBR-7	15 SBR-8	15 SBR-9	15 SBR-10	15 SBR-11	15 SBR-12	15 SBR-13	15 SBR-14	15 SBR-15	15 SBR-16	15 SBR-17	15 SBR-26
Tensile Strength	0	—	0	-	0	-	-	0	-	-	-	-	-	-	—	-	-	0
200% Modulus	0	+	0	+	0	0	+	+	0	0	0	0	-	-	++	+	0	0
Elongation	0	-	0	0	0	-	-	0	0	0	0	0	0	+	—	-	0	0
Taber Abrasion	0	++	0	+	0	+	++	++	+	+	++	+	+	++	++	+	+	++
Pico Abrasion	0	++	+	0	0	0	++	0	0	0	-	-	0	-	++	-	-	0
Tear Strength Die C	0	-	0	0	0	+	0	0	0	+	0	0	0	0	-	0	0	0
Tear Strength Die C-Hot	0	—	0	-	-	0	-	0	-	-	-	0	0	0	—	0	-	-
Tear Strength Trouser	0	0	0	-	-	0	0	0	0	-	0	0	+	++	—	-	-	0
Tear Strength Trouser-Hot	0	—	-	-	-	-	—	-	-	-	-	-	-	-	—	-	-	-
DeMattia Flex	0	—	—	-	-	-	—	-	-	-	-	0	+	+	—	-	0	0
DeMattia Flex Hot	0	—	-	-	-	-	-	-	-	-	-	-	0	+	+	-	-	0
Goodrich Flex ΔT	0	+	0	0	0	0	0	0	0	0	0	0	-	-	+	0	0	-
Goodrich Flex Dyn. Comp.	0	0	+	+	+	+	0	0	+	+	+	+	++	++	—	0	+	++
Compressibility 40%-R.T.	0	0	0	0	0	0	0	0	0	0	0	0	0	-	++	0	-	0
Compressibility 40%-70Hrs 250°F	0	-	0	-	-	0	0	0	0	-	0	-	-	-	++	0	-	-
Variables Mixing	Standard	Increased Batch Size	Decreased Batch Size	No Masticition	Increased Masticition	Reduced Banbury Mix Time	Increased Banbury Mix Time	Dump Temp. >220°F	-	-	-	-	-	-	-	-	Reduce Final Mix Time & Number of Passes	-
Compound	Standard	-	-	-	-	-	-	-	Treated Zinc Oxide	Predispersed Zinc Oxide	Spider Sulfur	Predispersed Sulfur & Santocure	Reduce Santocure	Reduce Sulfur	Increase Sulfur	N-220 Black	-	Polymer from another source

Legend

0 = no significant change - less than 10%
+ = 10 to 20% enhancement of property
- = 10 to 20% decrement in property
++ = Greater than 20% enhancement of property
— = Greater than 20% decrement in property

Table 15

Effect of Processing and Compounding Variables on Properties-Natural Rubber

Property	15 NAT-1	15 NAT-2	15 NAT-3	15 NAT-4	15 NAT-5	15 NAT-6	15 NAT-7	15 NAT-8	15 NAT-9	15 NAT-10	15 NAT-11	15 NAT-12	15 NAT-13	15 NAT-14	15 NAT-15	15 NAT-16	15 NAT-17	15 NAT-18
Tensile Strength	0	0	0	0	0	0	--	0	-	0	0	0	0	-	-	-	-	0
200% Modulus	0	+	+	0	0	0	+	0	+	+	+	+	0	-	++	+	+	+
Elongation	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	-	0	0
Taber Abrasion	0	-	+	+	+	+	+	+	++	++	++	+	++	++	--	--	--	--
Pico Abrasion	0	++	+	0	+	0	+	0	++	++	0	+	+	++	0	0	0	0
Tear Strength Die C	0	--	0	0	0	0	-	0	-	-	0	-	0	+	--	--	-	-
Tear Strength Die C-Hot	0	0	0	0	+	0	0	0	0	0	0	0	0	0	-	-	0	0
Tear Strength Trouser	0	++	+	++	+	+	+	++	-	++	+	+	+	++	--	+	+	+
Tear Strength Trouser-Hot	0	+	+	-	-	+	0	0	0	0	0	0	0	++	--	-	0	0
DeMattia Flex	0	0	0	+	0	0	+	+	+	0	0	0	+	++	++	++	++	+
DeMattia Flex Hot	0	0	0	0	0	0	0	+	+	0	0	0	++	++	--	0	0	-
Goodrich Flex ΔT	0	0	0	0	0	0	-	+	0	0	0	+	0	0	++	+	+	+
Goodrich Flex Dyn. Comp	0	-	-	-	-	-	0	0	-	-	-	-	+	++	--	-	-	-
Compressibility 40%-R.T.	0	-	0	0	0	0	-	0	0	-	++	+	0	0	++	++	+	++
Compressibility 40%-70Hrs 250°F	0	0	0	0	0	0	0	0	0	0	0	0	--	--	++	0	0	0
Variables Mixing	Standard	Increased Batch Size	Decreased Batch Size	No Mastication	Increased Mastication	Reduced Banbury Mix Time	Increased Banbury Mix Time	Dump Temp. >220°F	-	-	-	-	-	-	-	-	-	-
Compound	Standard	-	-	-	-	-	-	-	Treated Zinc Oxide	Predispersed Zinc Oxide	Spider Sulfur	Predispersed Sulfur & Santocure	Reduce Santocure	Reduce Sulfur	Increase Sulfur	N-220 Black	Reduce Final Mix Time & Number of Passes	N-234 Black

Legend

0 = no significant change - less than 10%
\+ = 10 to 20% enhancement of property
\- = 10 to 20% decrement in property
++ = Greater than 20% enhancement of property
-- = Greater than 20% decrement in property

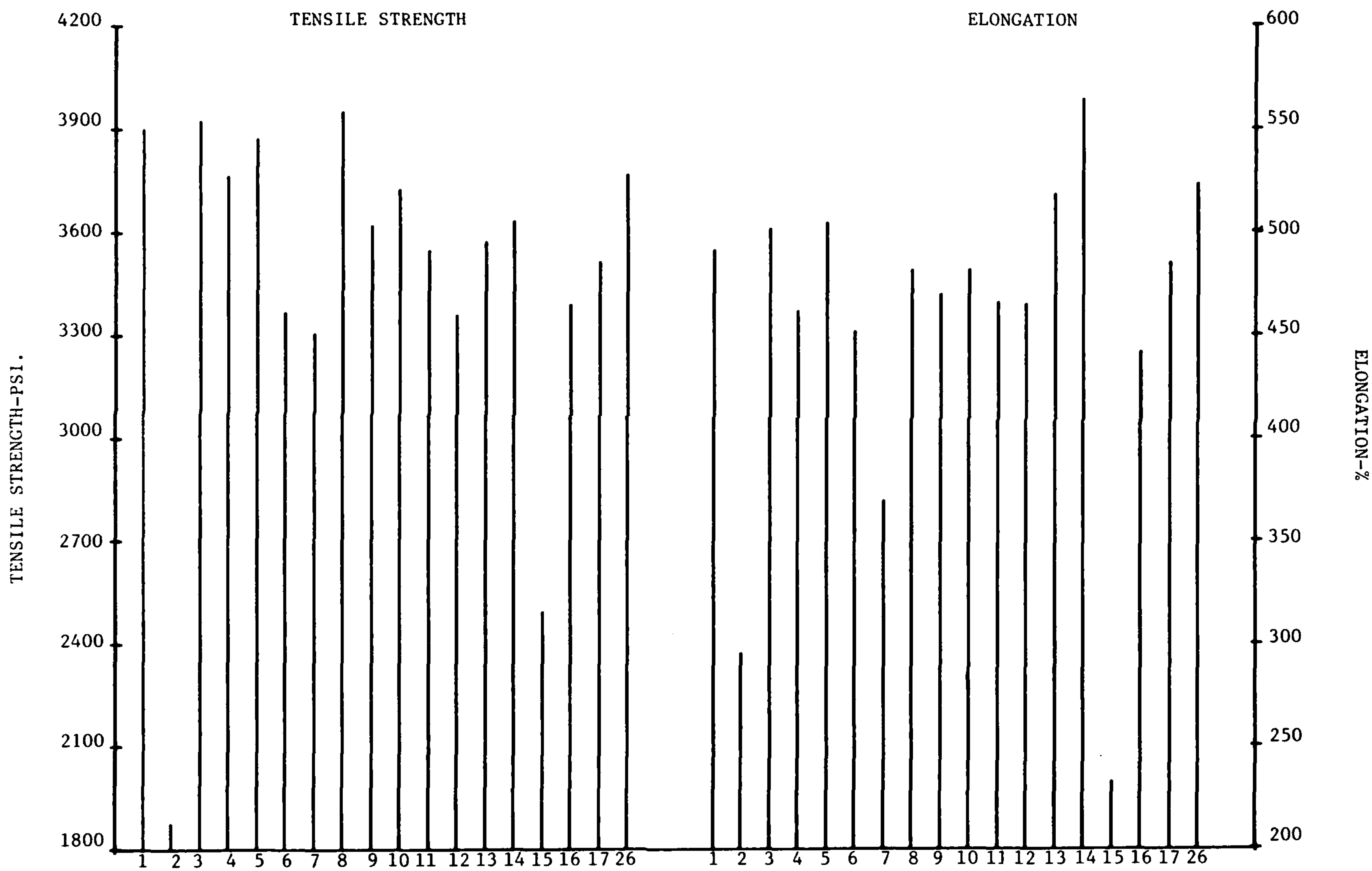


Figure 4. Tensile Strength and Elongation—SBR

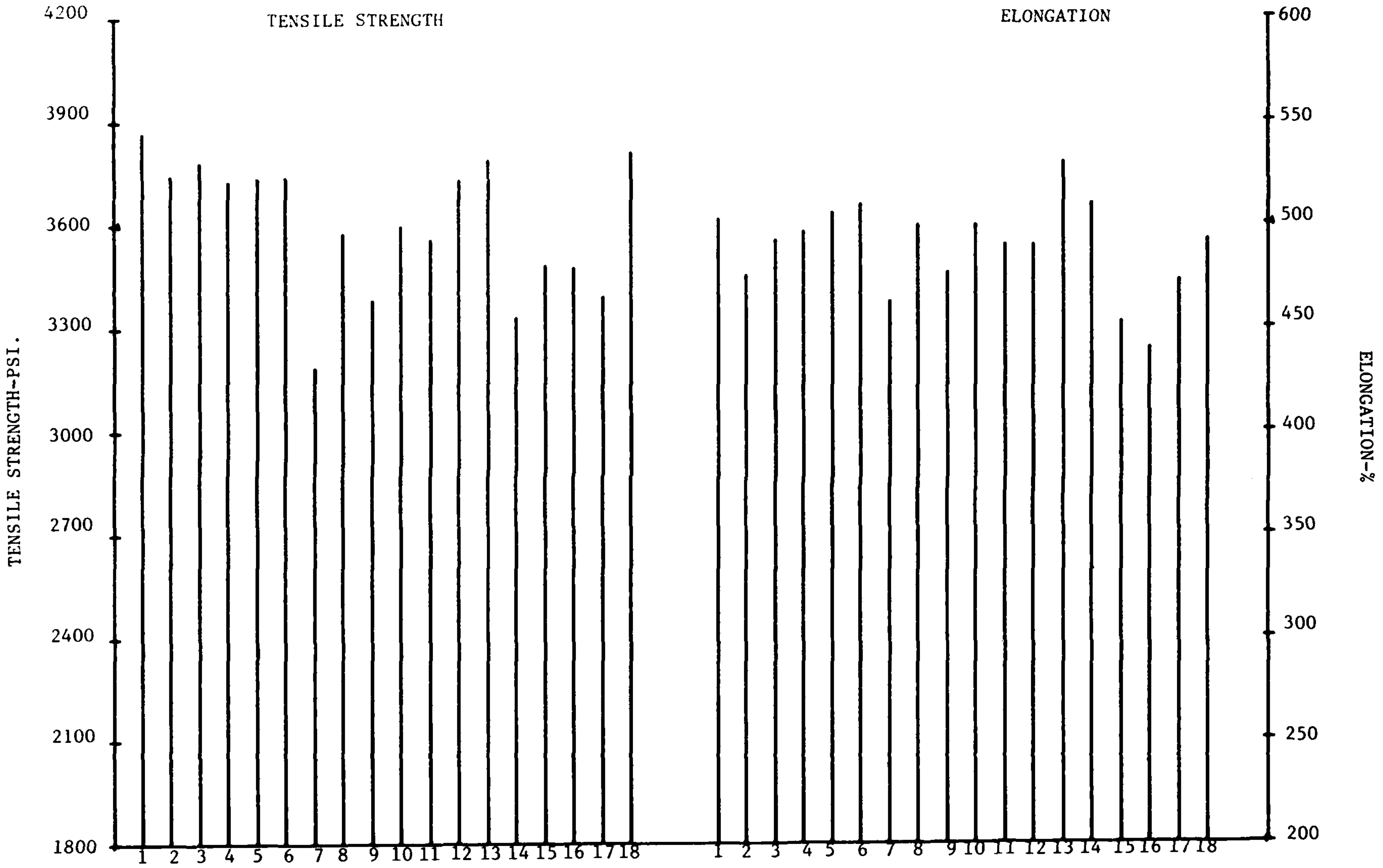


Figure 5. Tensile Strength and Elongation—NR

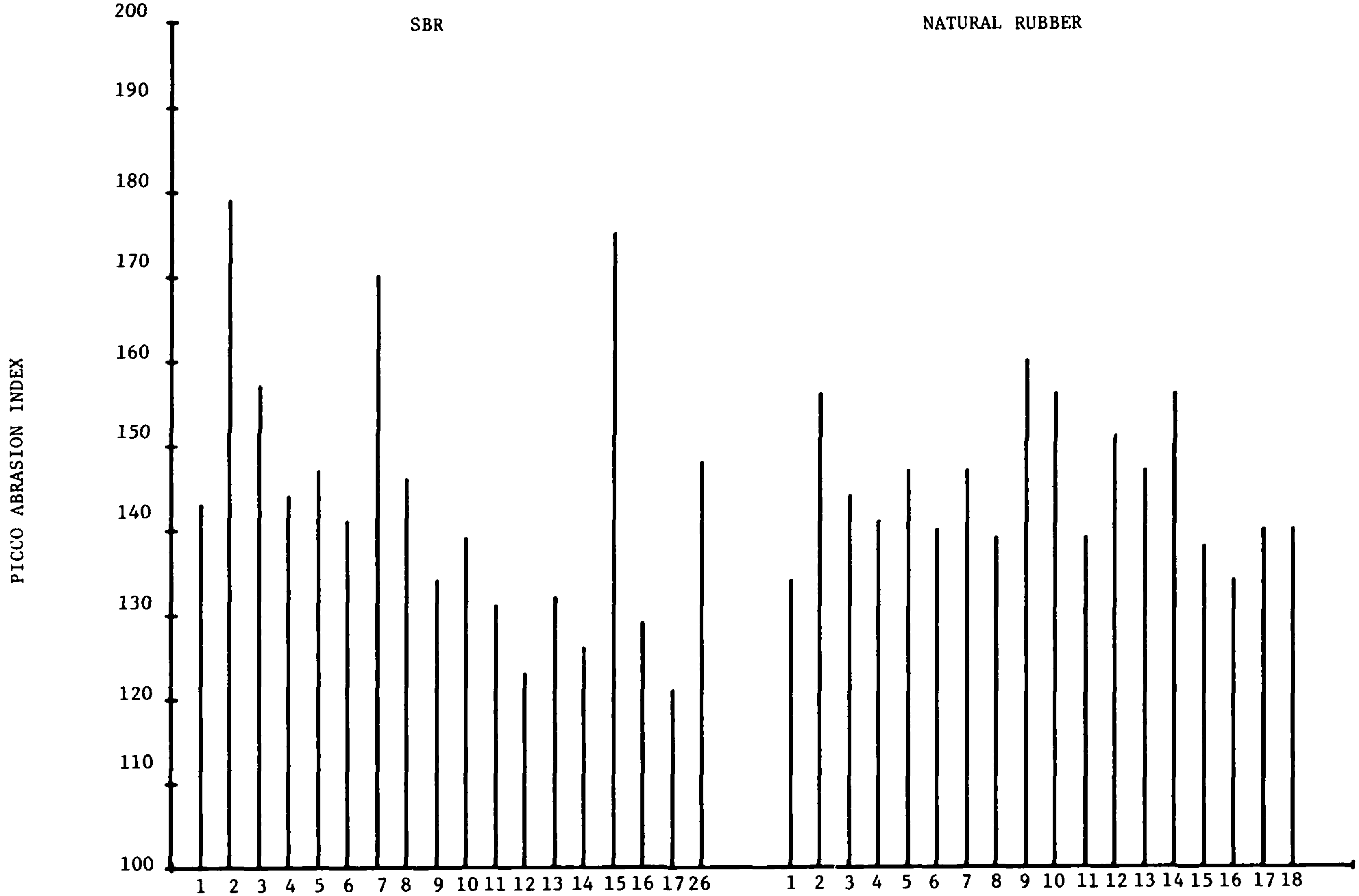


Figure 6. Pico Abrasion Index—SBR and NR

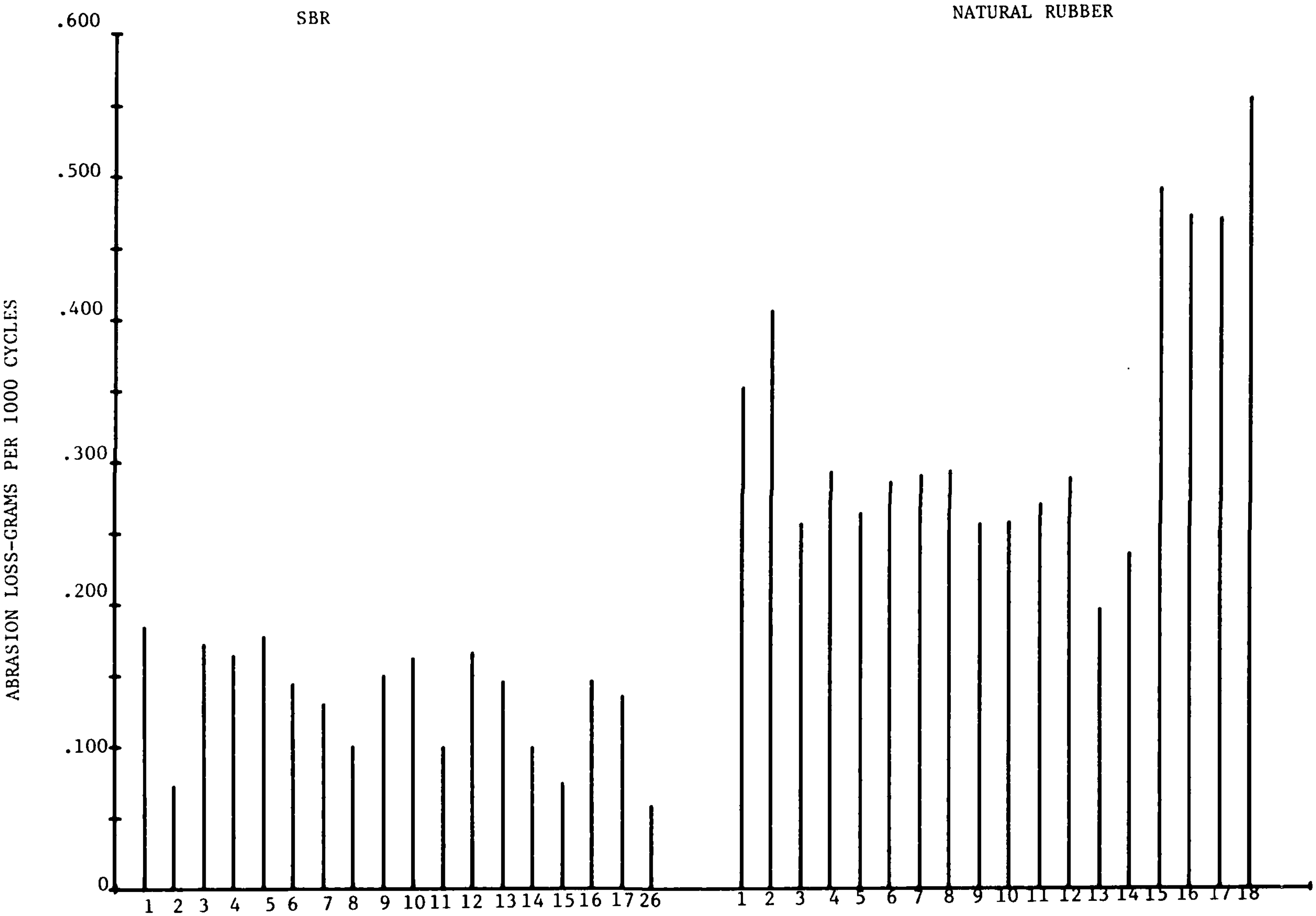


Figure 7. Taber Abrasion Loss—SBR and NR

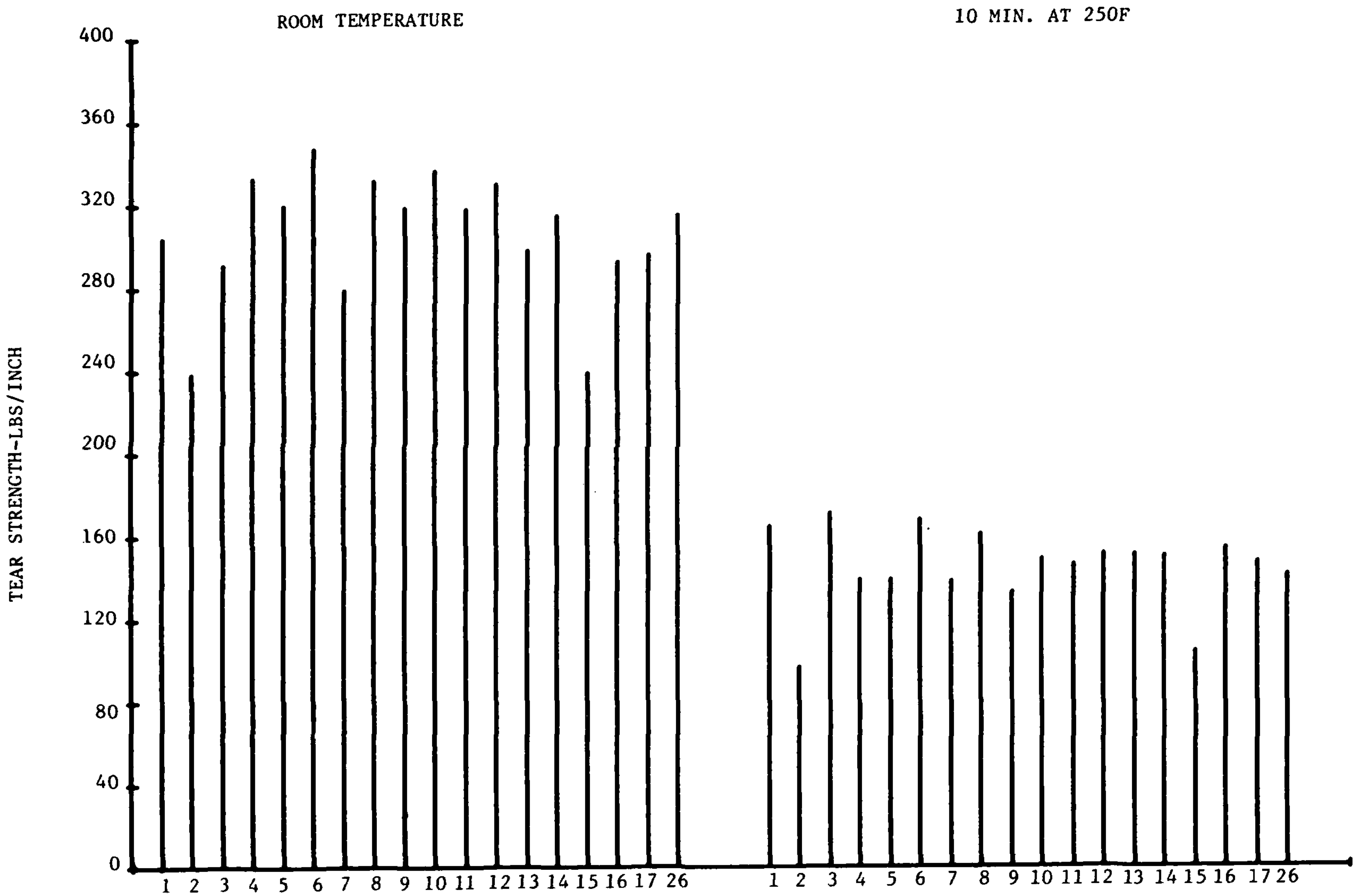


Figure 8. Die C Tear—SBR

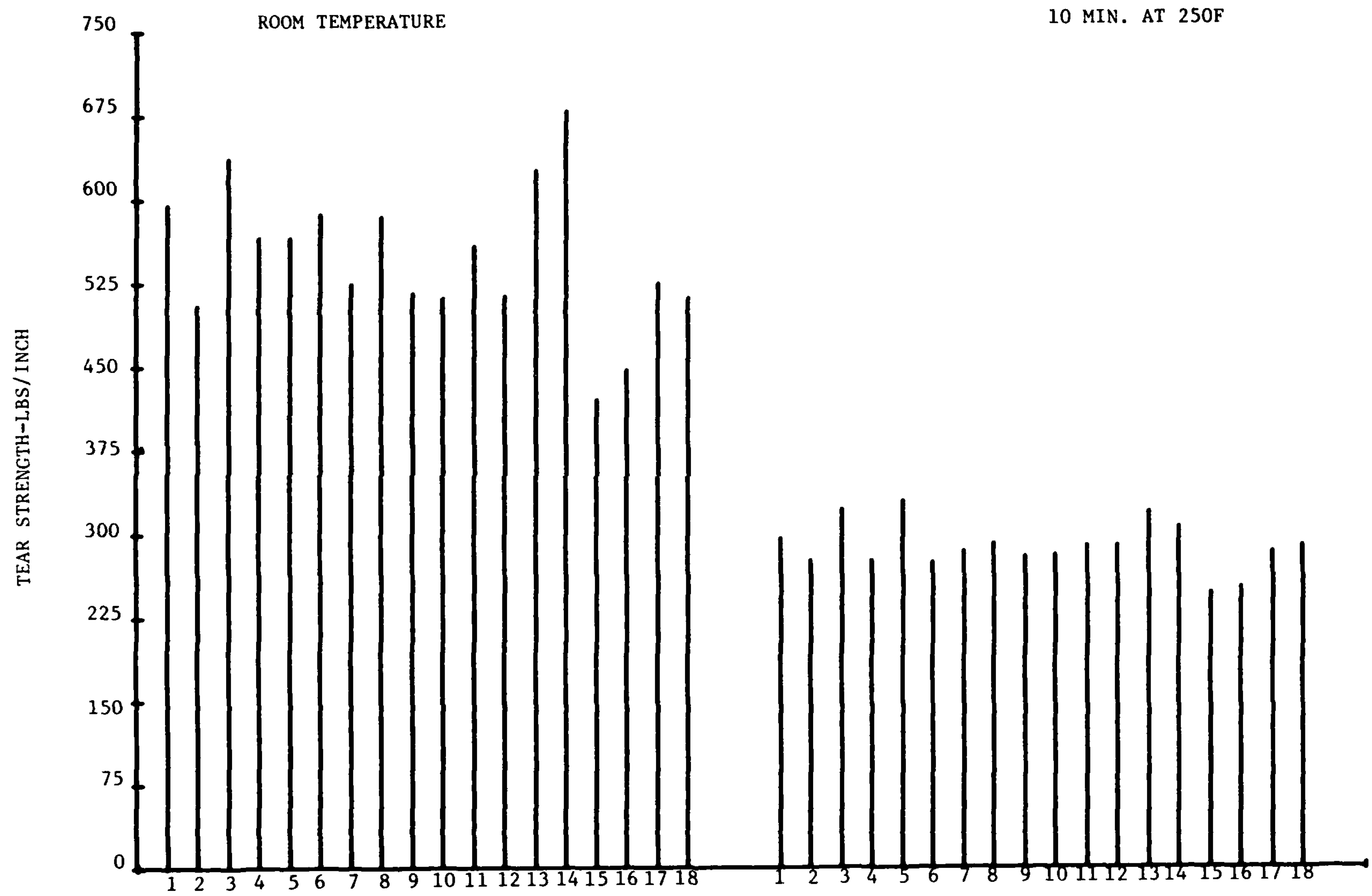


Figure 9. Die C Tear—NR

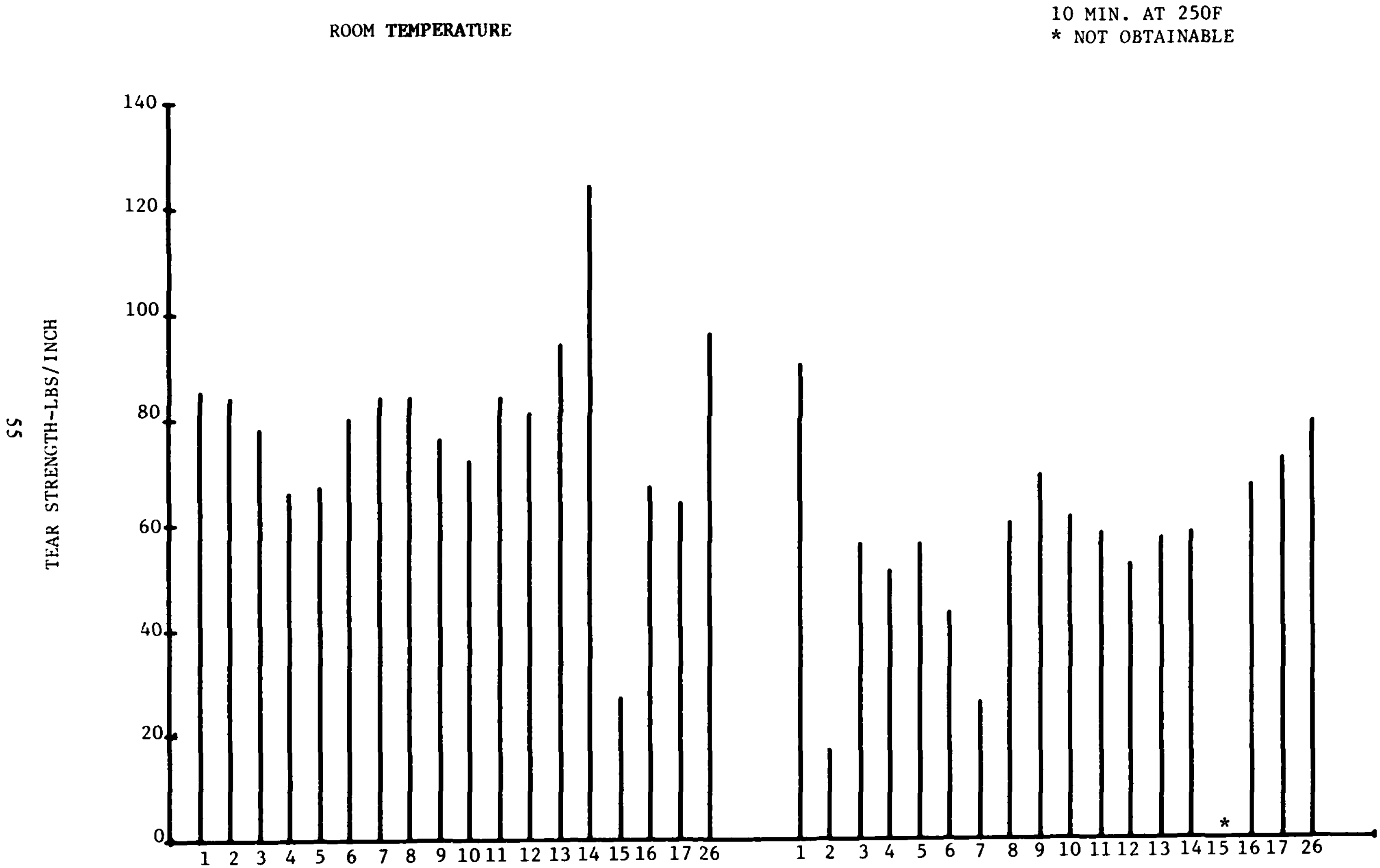


Figure 10. Trouser Tear--SBR

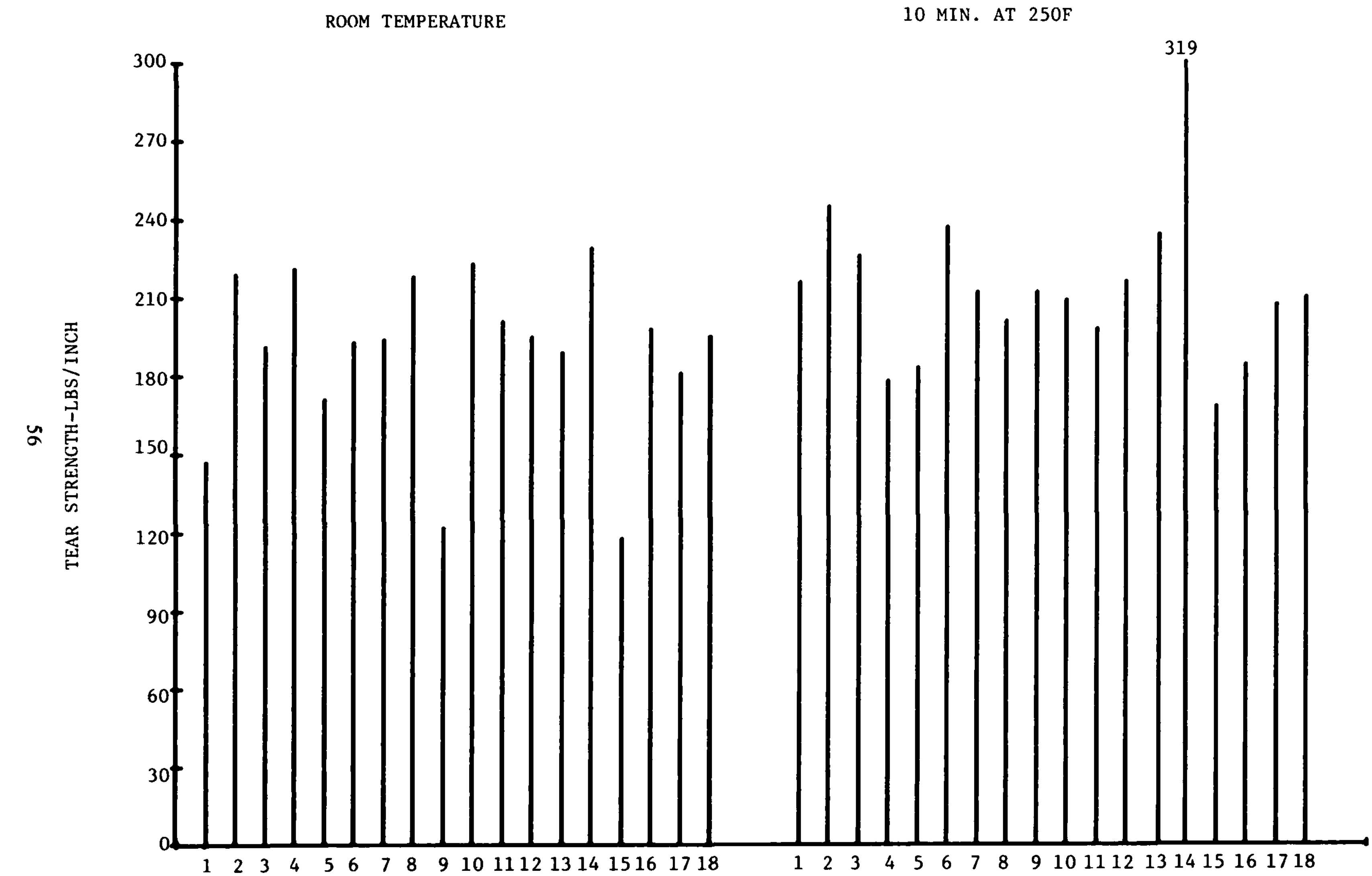


Figure 11. Trouser Tear—NR

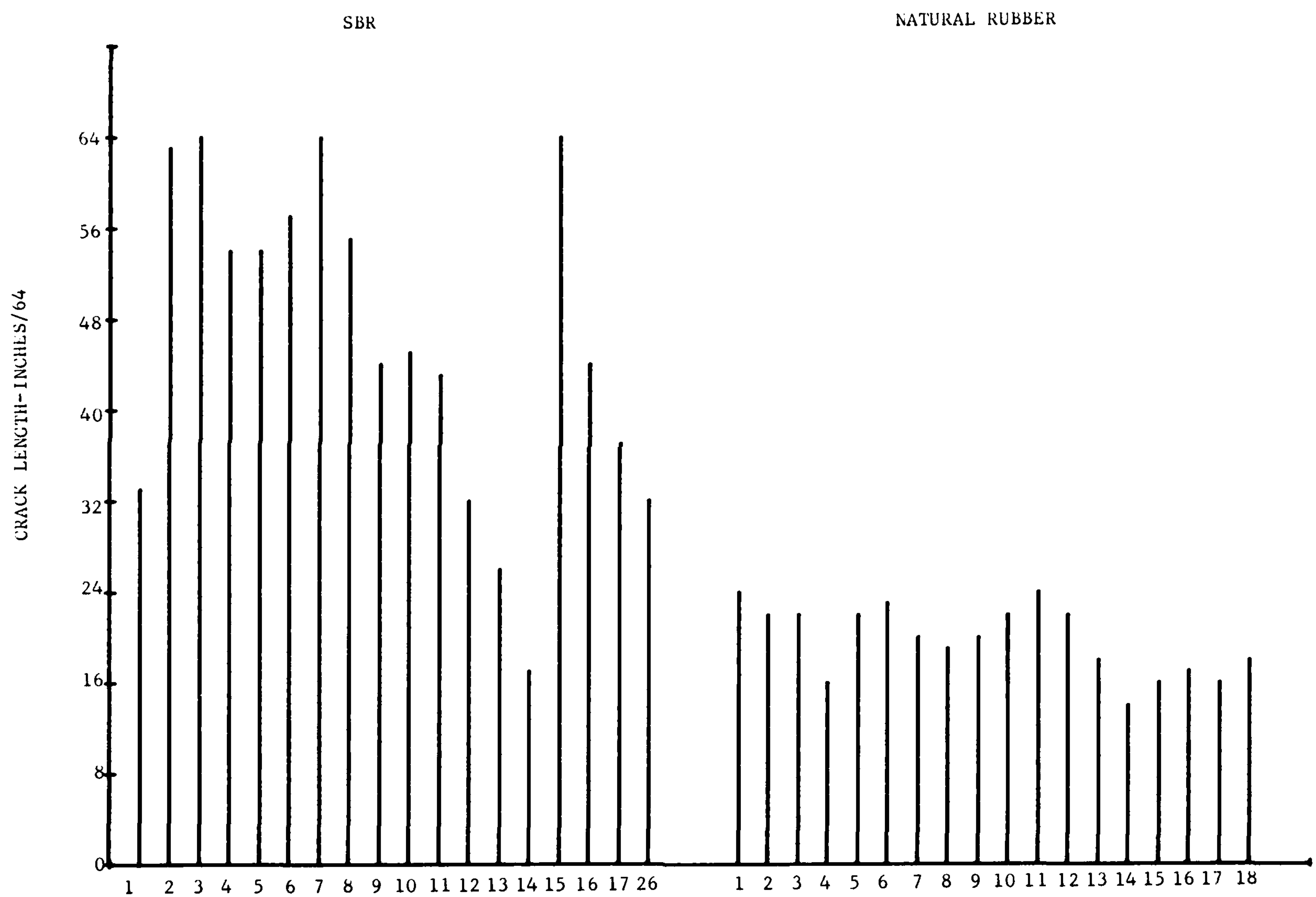


Figure 12. DeMattia Flex After 6000 Cycles

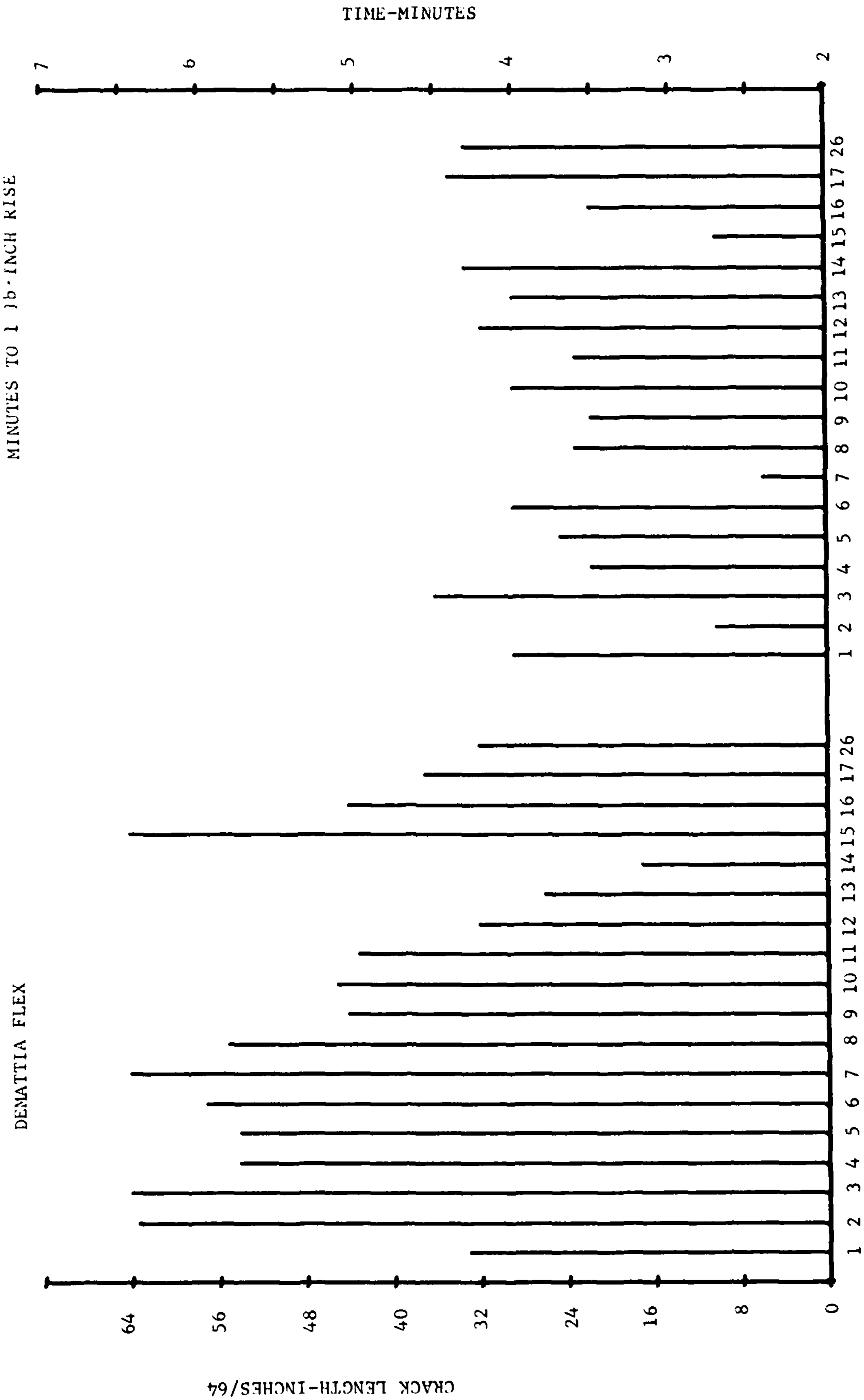


Figure 13. DeMattia Flex vs Scorch Rate—SBR

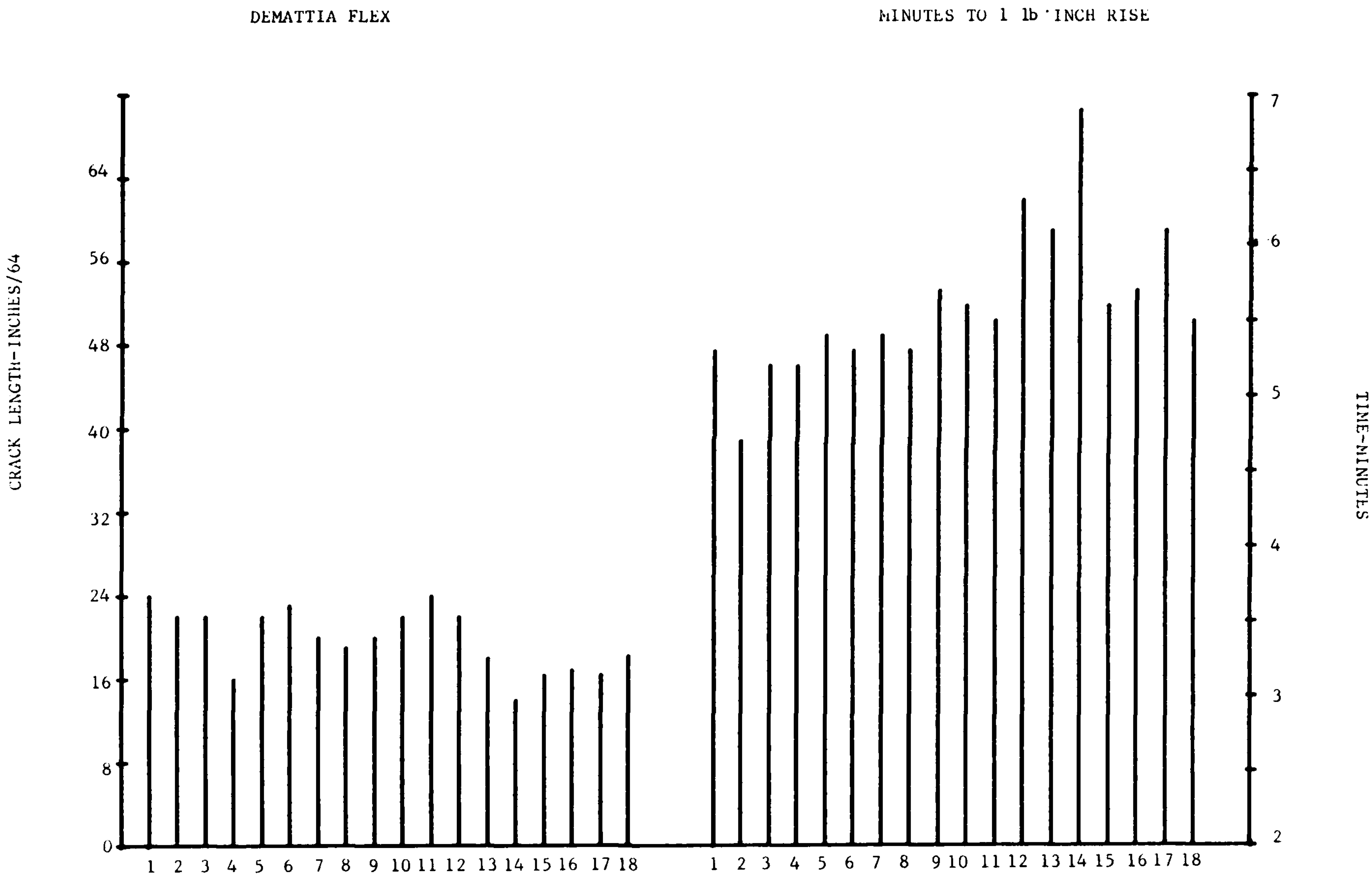


Figure 14. DeMattia Flex vs Scorch Rate—NR

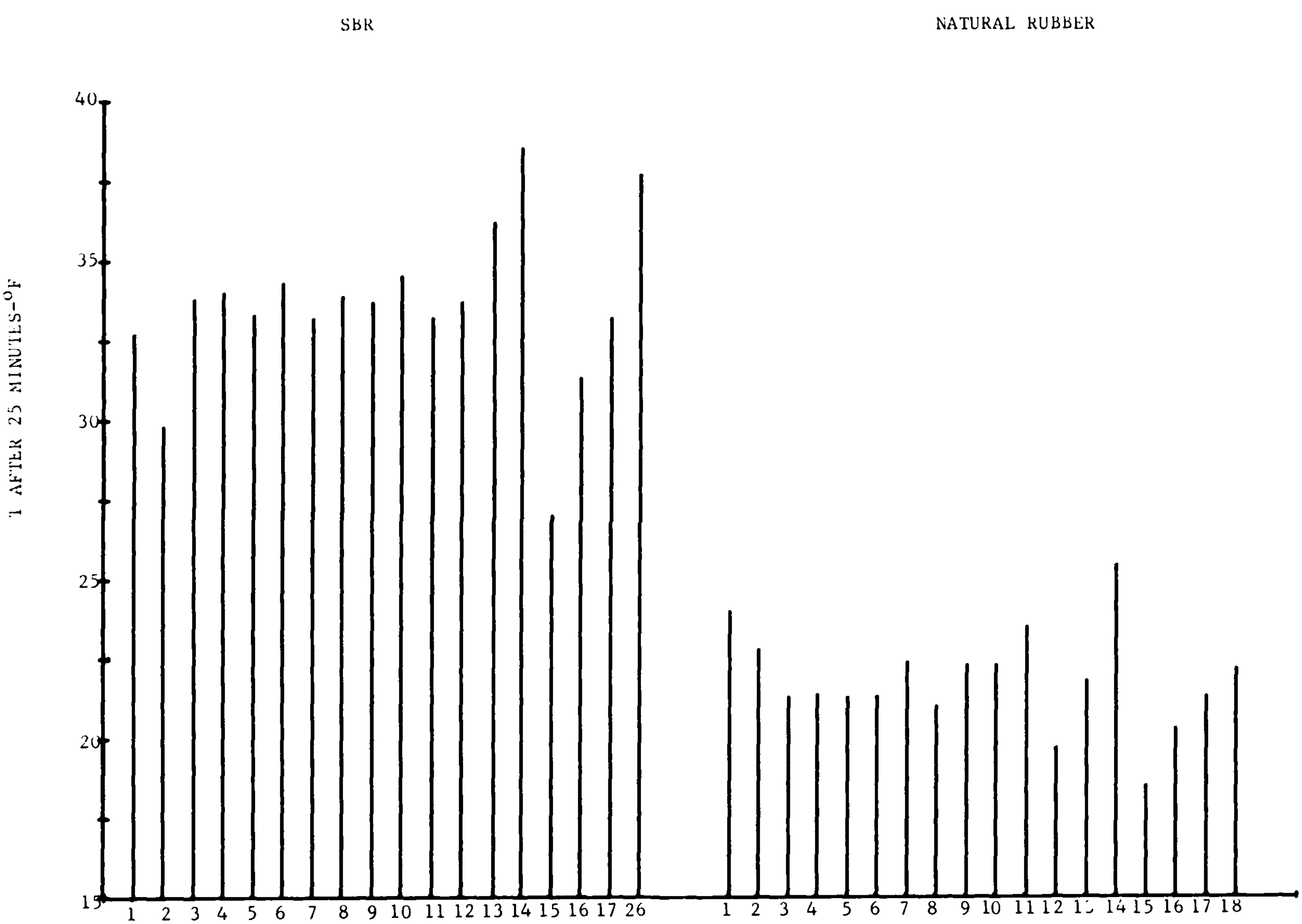


Figure 15. Goodrich Flex -ΔT–SBR and NR

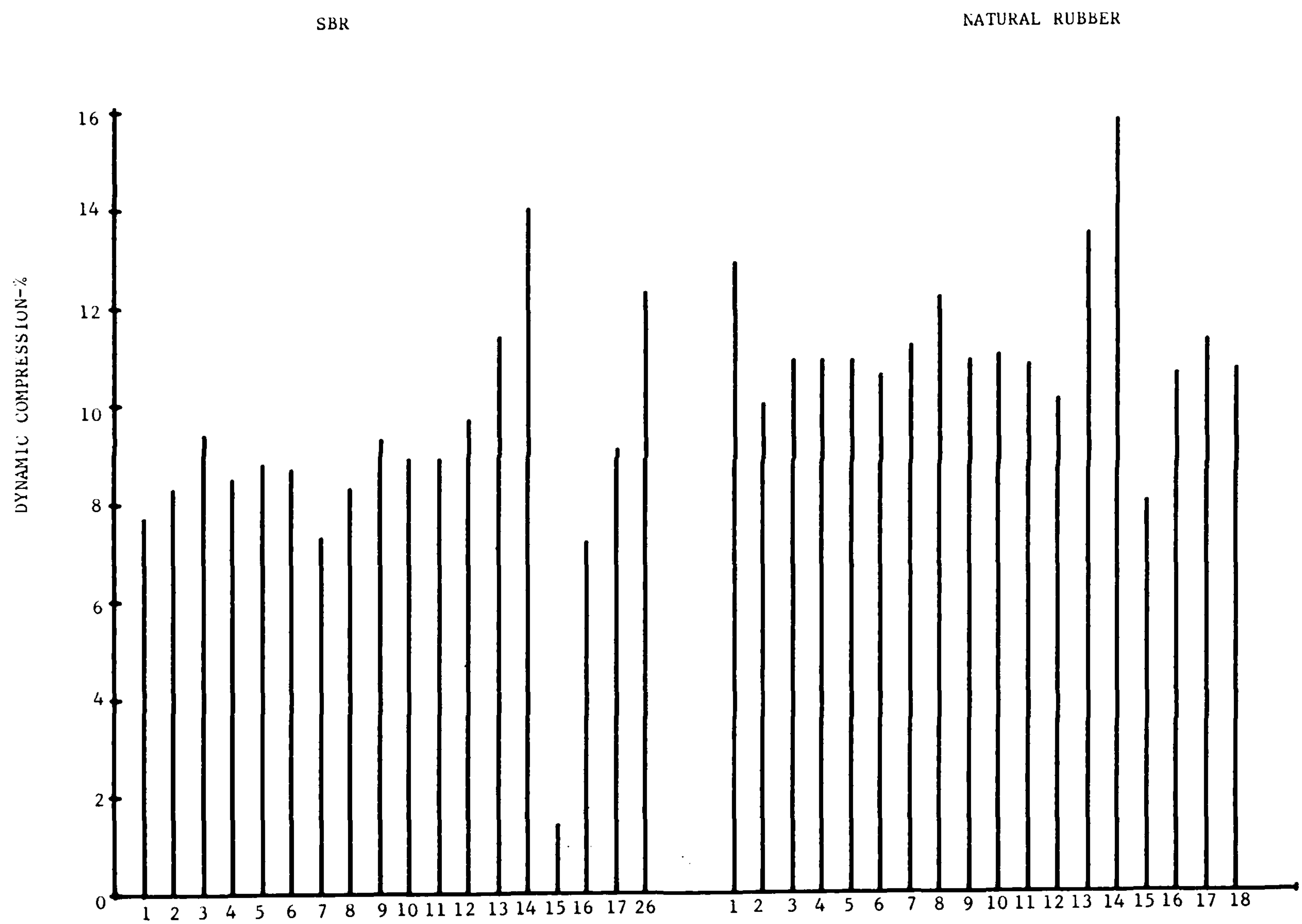


Figure 16. Goodrich Flex—Dynamic Compression—SBR and NR

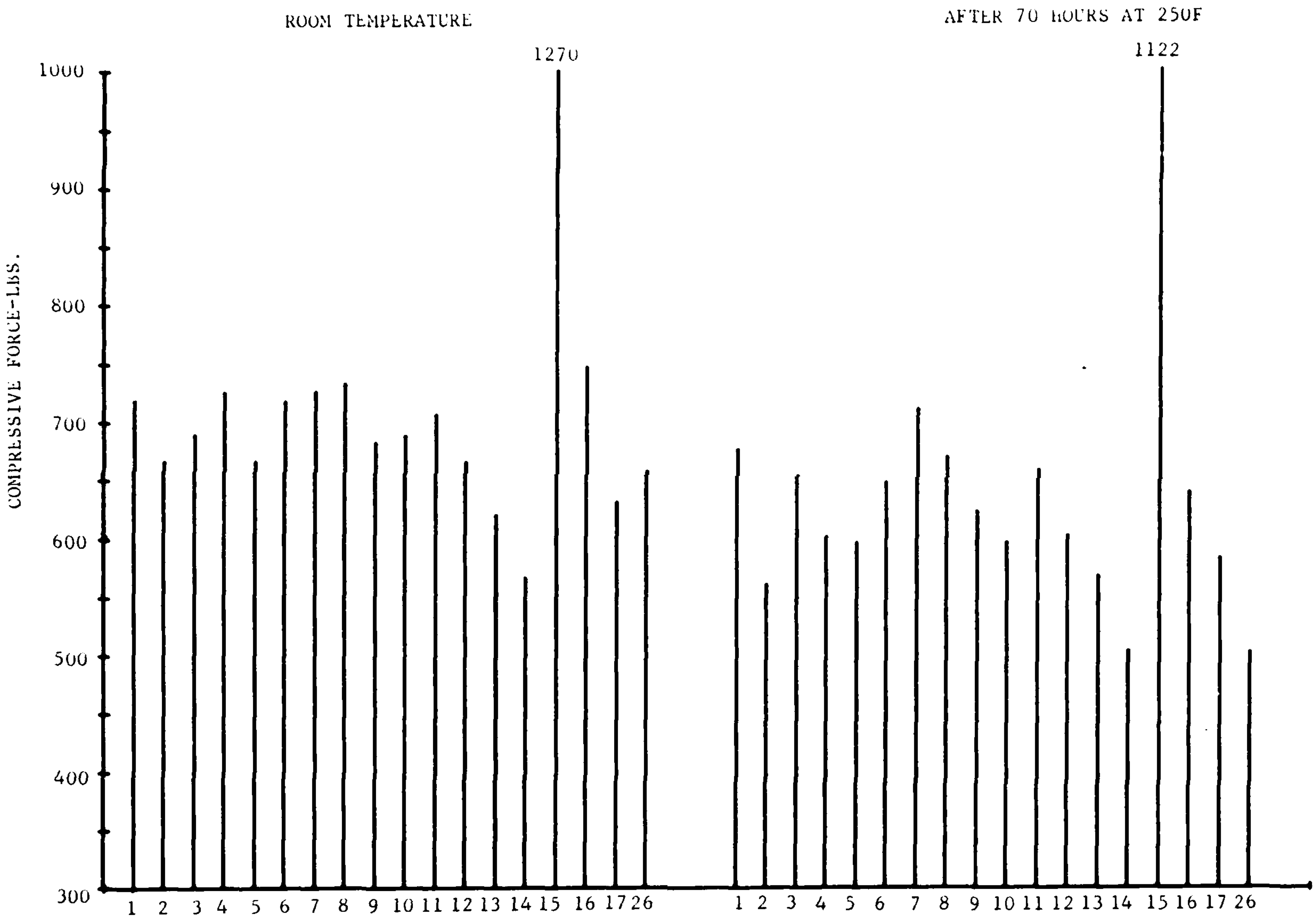


Figure 17. Compressibility of SBR Compounds; 40% Compression

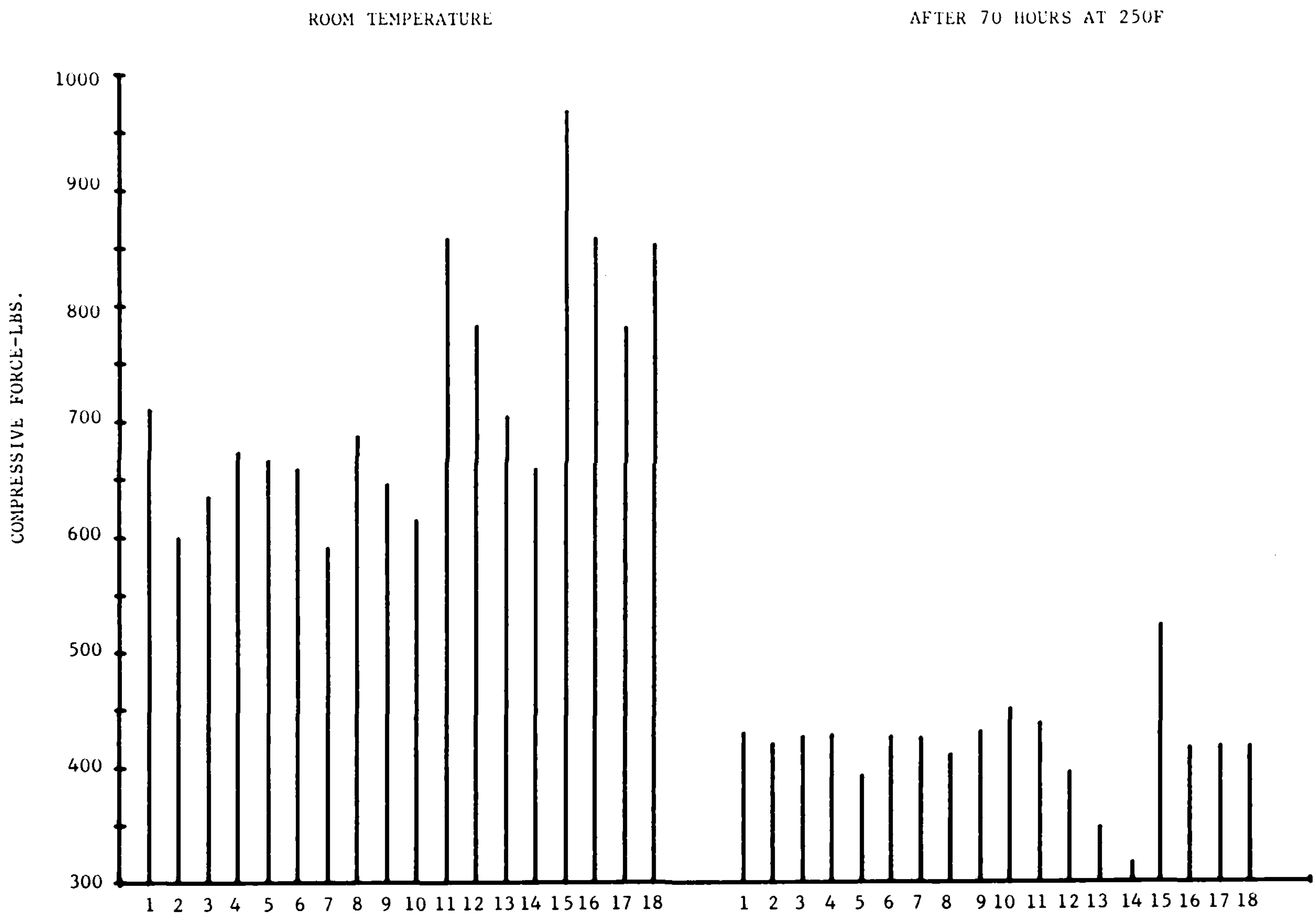


Figure 18. Compressibility of NR Compounds; 40% Compression

III. DISCUSSION

6. Rheology and Dispersion. Rheological data for the 18 SBR compounds, as summarized in Table 4, indicate that overloading of a Banbury mixer has the most significant effect on processability, while other formulation or procedural variables evidenced negligible to slight influences. Compound 2 (overloading) displayed a Mooney viscosity in excess of 200, the lowest T_{90} and highest M_L in the Monsanto rheometer and the poorest dispersion. Compound 7, wherein the mix cycle was extended to 15 min, showed a similar trend, but final dispersion was observed to be significantly better. When the Santocure level was reduced to 1 phr, as in compound 13, the T_{50} and T_{90} were somewhat higher than noted for the control. However, properties measured on the Mooney viscometer were normal, and dispersion was judged good. Increasing the sulfur content as in compound 15, or using an alternate ISAF carbon black (N220) in lieu of SAF-N110 as in compound 16, resulted in expected reductions in the Mooney scorch time.

Examination of the rheological data for the NR compounds (Table 5) reveals that processing is less subject to formulation and procedural variations than observed for the SBR compounds. While compound 2 again displayed low T_{90} and high M_L readings, Mooney viscometer data was essentially equivalent to that for the control. Compounds 13-15, wherein curative content was changed, evidenced higher Mooney scorch values and, except for compound 14, T_{90} (in minutes) was also greater than noted for others. Monsanto rheometer curves as depicted in Figures 19 through 21 more vividly highlight differences within batches of the same compound and among the compounding variables selected in this program than is evident from the data of Tables 4 and 5. When the three batches of compound 15SBR-2 were individually mixed (Figure 19), two cure curves (A & C) were practically superimposed while the third (B) displayed a slightly lower initiation rate but a higher profile. Curves for the NR equivalent—15NAT-2 (Figure 20) were noticeably different in all aspects. Here, the differences were not unexpected since the effect of overloading the Banbury mixer was being studied. Although the mix cycle was shortened for compound 15SBR-6, all three curves showed close agreement as demonstrated in Figure 21. The fact that all but one compound (15SBR-2) received a dispersion rating of six or better underscores the efficiency of Banbury mixing even under the poorest process control conditions.

To augment the evaluation and analysis of dispersion of compounding ingredients, photographs appearing in Appendix A were taken from the SEM with magnification being approximately the same as used in the stereo microscope; i.e., 60 X. Since the SEM provided better illumination and depth of field, a more critical study was possible. Photograph B in Group 5 clearly shows the difference between torn and cut surfaces for compound 15SBR-10. The left one-third of the view contains a portion of the hand-made cut, while the remainder highlights the torn surface.

The photos of compound 15NAT-1, the control contained in Group 1, illustrate good distributive and dispersive mixing, the minor constituents are adequately randomized, and agglomerates have been broken down sufficiently to negate any tendency to concentrate in certain areas. Insufficient dispersive mixing is evident in Group 2 photos of compound 15SBR-2. Overloading of the Banbury mixer restricted breakdown resulting in a final mixture that evidenced widely varying properties. Increasing the mixing time as shown in Group 3 photos for compound 15SBR-7 produced a more even appearing torn surface area, but the presence of pinholes lowered the overall rating.

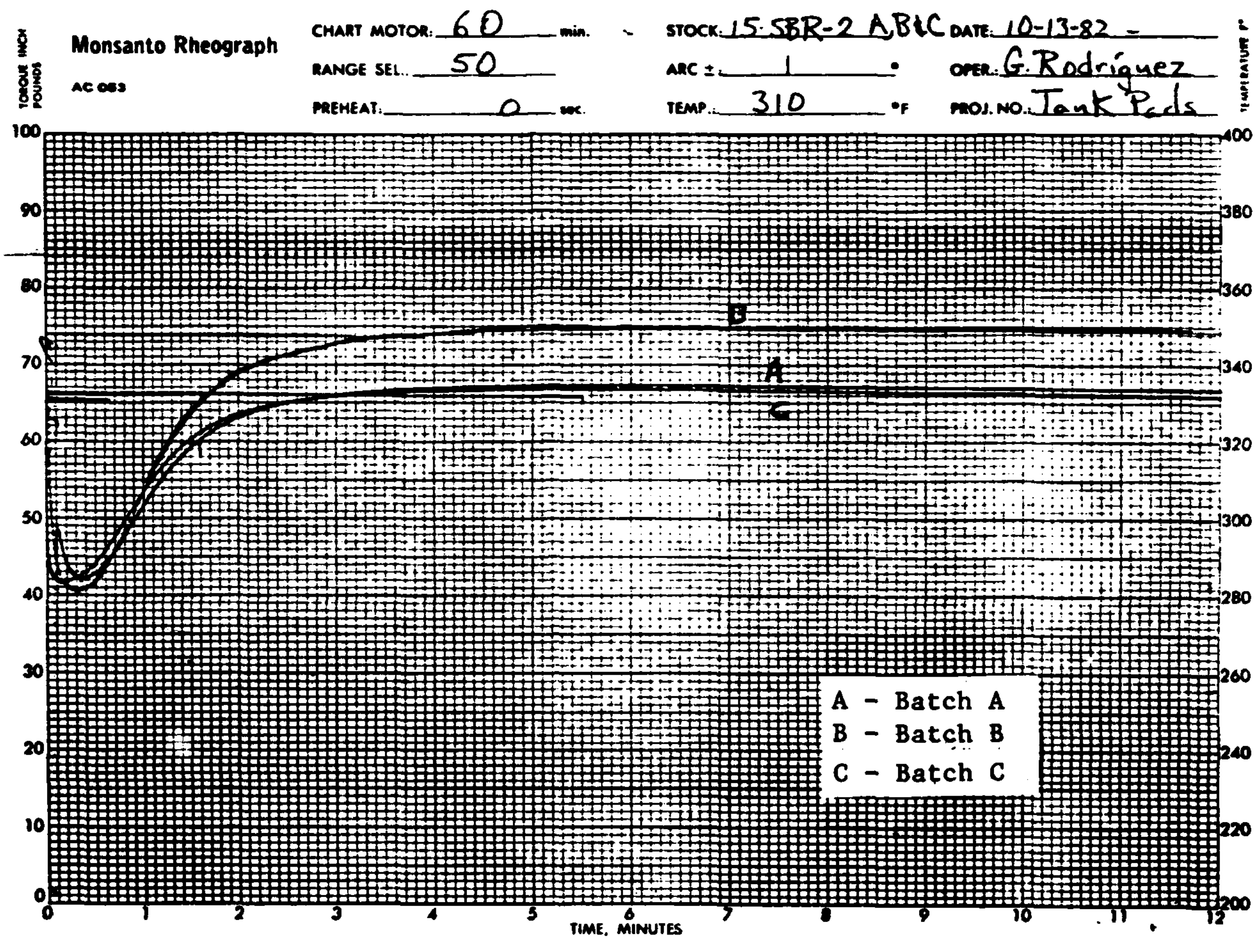


Figure 19. Monsanto Rheometer Curve—Compound 15SBR-2

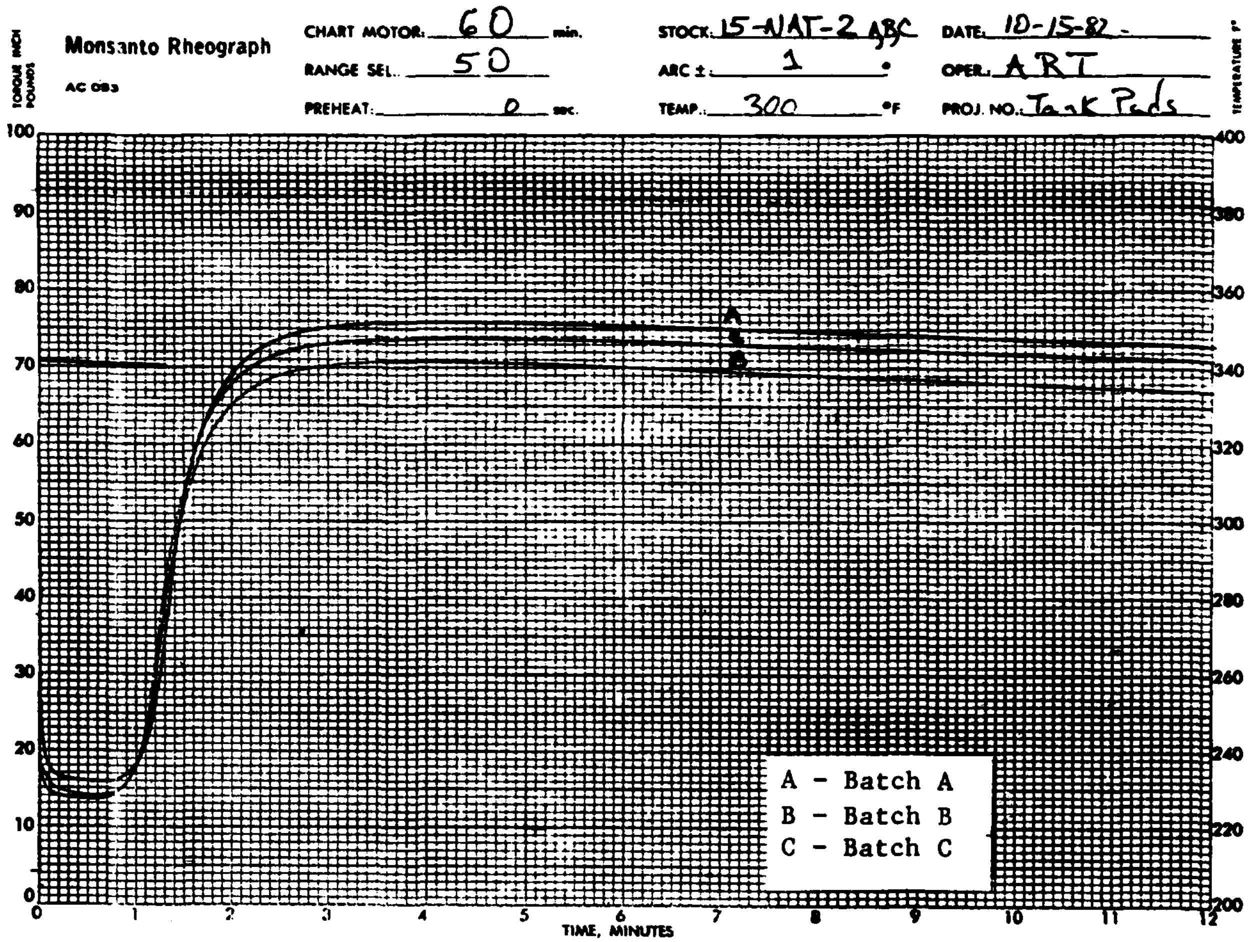


Figure 20. Monsanto Rheometer Curve—Compound 15NAT-2

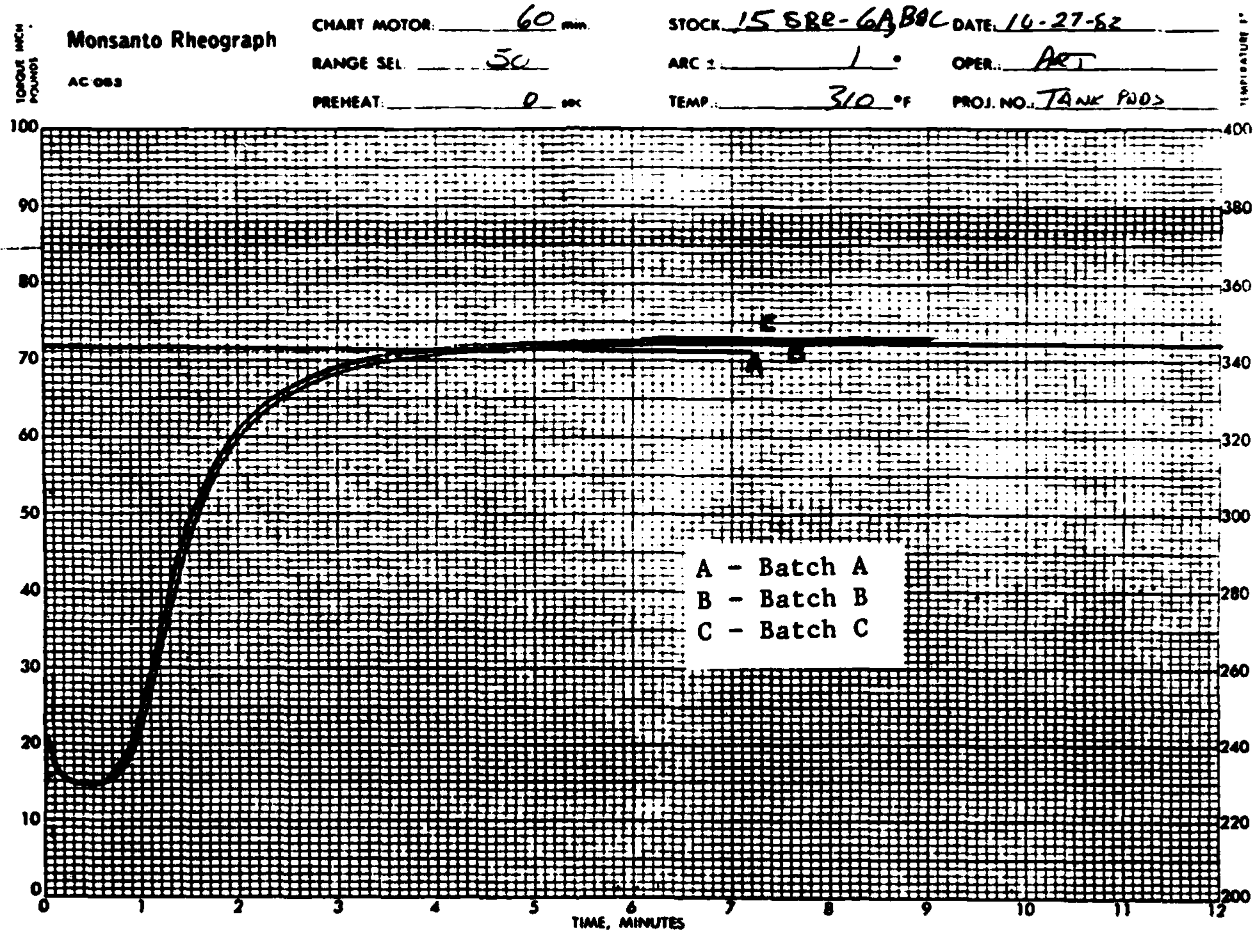


Figure 21. Monsanto Rheometer Curve—Compound 15SBR-6

When allowing the mixing temperature to rise above 220 degrees F as in compound 15NAT-8 and shown in Group 4 photos, the critical shear rate/viscosity/temperature relationship is disrupted and dispersion is restricted. If curing ingredients are present in the mix, as was the case with all SBR compounds, partial cross-linking can occur, further inhibiting dispersion. Use of predispersed ingredients, such as zinc oxide in compound 15SBR-10 (Group 5 photos), does not substantially alter visual interpretation of dispersion; appearance was essentially similar to that of the control. Intentional inclusion of excess sulfur, as in compound 15SBR-15 (Group 6 photos, Appendix A), resulted in relatively good dispersion, but this is nullified by the large number of pinholes on the torn surface—more than any other compound.

Compounds 15SBR-16 and 15NAT-16, wherein ISAF black (N220) was substituted for the N110 used elsewhere, are depicted in the final two groups of SEM photos—7 and 8. Considering that the particle size is coarser, dispersion is good, but adjustment in the mixing cycle is advisable. The SEM photographs do not provide any readily distinguishable difference in dispersion between SBR and NR compounds. Visual observations must be correlated with physical data to obtain a meaningful interpretation of performance potential.

7. Tensile Strength and Elongation. Tensile strength and elongation data for the 18 SBR and NR compounds contained in Tables 6 and 7 are represented graphically in Figures 4 and 5. It is evident here that, particularly in the case of SBR compounds, these property values correlate with rheological profiles. Compounds 15SBR-2, -7, and -15 displayed significantly lower tensile strength and elongation, again demonstrating the effect of Banbury mixer overloading, extended mixing cycle, and increased sulfur content, respectively. Reduction of the mixing cycle (15SBR-6) resulted in a noticeable lowering of tensile strength, but elongation was only slightly reduced. Compound 15SBR-14 (lower sulfur content) produced the highest ultimate elongation—566 percent, as opposed to 493 percent for the control. Other variations in properties evident in Figure 4 are not sufficiently significant to correlate with real effects of the respective mixing or chemical factors.

Similar data for the equivalent NR compounds, depicted in Figure 5, clearly shows that the mixing and curing of this rubber is more consistent with ultimate properties less affected by the variables inserted in this program. Extended mixing of compound 15NAT-7 did produce a noticeable lessening in tensile strength, but elongation was only marginally affected. Even overloading of the Banbury mixer (15NAT-2) did not substantially influence these properties. Changing the sulfur or Santocure level as in compounds 15NAT-13 through -15 resulted in values which are perhaps statistically significant, but as stated earlier, optimum cure selection based on individual rheometer curves was not employed here.

8. Abrasion Testing. Data accumulated in abrasion testing using the Pico method are graphically displayed in Figure 6. The obviously more consistent index values for the NR compounds can be attributed primarily to the fact that curatives were added during final mill mixing and not during the Banbury mixer cycle, as was the case with the SBR formulations. Significantly higher indices as computed from lower abrasion losses were observed for 15SBR-2, 15SBR-7, and 15SBR-15, continuing the trend shown by these compounds in earlier comments on tensile strength and elongation. Other variations, such as substituting alternate ingredients and lesser amounts of curative and accelerator, resulted in lower ratings than obtained for the standard 15SBR-1. All Pico ratings for the NR variants equalled or exceeded that of the control, indicating that delayed addition of the curatives, combined with the inherent better mixing qualities of NR, minimized any ultimate impact on abrasion resistance.

The corresponding bar graph (Figure 7), depicting abrasion losses for SBR and NR according to the Taber procedure, highlights the across-the-board, better performance of the former series of compounds. All losses for the SBR compounds were equal to or lower than that of the control and particularly noticeable in the cases of 15SBR-2 (Banbury mixer overloading), 15SBR-8 (uncontrolled temperature rise), 15SBR-11 (spider sulfur), 15SBR-14 (reduced sulfur), and 15SBR-15 (increased sulfur). Effects noted in the last three instances tend to indicate that type and level of sulfur can influence abrasion properties, although the high-low sulfur comparison (15SBR-14 and -15) appears to be an unexplainable anomaly. Cessation of production of Firestone's SBR-1500 mandated establishment of another source. Further work with Copolymer's equivalent will be necessary to validate whether this material does produce lower abrasion losses (15SBR-1 vs. 15SBR-26). Cursory inspection of the NR data of Figure 7 would give the impression that the compounding and mixing factors relative to compounds 15NAT-3 through 15NAT-14 all contributed to an improvement in abrasion resistance of the respective compound. However, these changes have had no significant favorable impact on tensile properties, and data are inadequate for final judgment. Effects on other properties must also be considered. It is apparent that Banbury mixer overloading, high sulfur, and use of alternate blacks (15NAT-2, -15, -16, and -18, respectively) have a negative effect on abrasion resistance. In comparing the Taber procedure versus the Pico method, the former is more discriminating and to be favored but only as a comparative index of performance on relatively smooth surfaces. Agreement with susceptibility to cutting, chunking, and chipping is not possible, but recent field performance studies on tires have shown that correlation with Taber results obtained in the laboratory is more favorable than with Pico results.

9. Tear Strength. Good tear strength, a property considered important in tank pad compounds, has traditionally been measured according to the so-called ASTM Die C procedure. In this work, a modified trouser tear test as detailed earlier, was included to ascertain potential merit in establishing additional performance criteria. Data generated from the two tests as contained in Tables 8 and 9 are shown graphically in Figures 8 through 11 to emphasize observations. Room temperature or initial values and results after heat aging 10 min at 250 degrees F appear side-by-side for each rubber/test combination. When the Die C results for SBR and NR compounds are viewed simultaneously, ignoring the difference in magnitude of the initial values, it is quite apparent that the relative effect of heat aging is essentially and proportionately the same for both rubbers. Among the SBR formulations, compounds 15SBR-2, -7, and -15 displayed noticeably lower room temperature values, but only compounds 2 and 15 continued to show this tendency after the heat aging. Compounds 15NAT-3, -13, and -14 evidenced Die C room temperature values higher than the control, and those for 15NAT-2, -15, and -16 were significantly lower. However, after heat aging, all compounds displayed losses that were confined to a narrow range.

The inherently better tear resistance of NR is again evident when the modified trouser tear test results are compared side-by-side as in Figure 10 and 11. The test procedure not only highlights effects of previously referenced procedural or chemical variations, but also focuses on what could either be anomalies or real effects not previously encountered. Here, the most noticeable is the significantly higher retention of NR tear strength after heat aging for 10 min at 250 degrees F. Particularly, 15NAT-14 (reduced sulfur content) and problem compounds 2, 7, and 15 all performed as well as or better than their room-temperature counterparts. Low initial values for the NR control (15NAT-1) and the variant containing treated zinc oxide (15NAT-9) warrant further investigation. Among the SBR compounds, 15SBR-1, the control, appeared unaffected by the heat treatment, and the reduced sulfur variant, 15SBR-14, gave an unusually high initial value. Otherwise, the pattern displayed by the group SBR-2, -7, and -15 was as expected, while results for others were inconclusive.

Obviously, the future merit of the modified trouser tear test cannot be decided here. However, it is apparent that in order for Die C and trouser tear tests to be effective, they must be monitored closely and that further work is necessary to clarify cause/effect relationships when conducting studies of this nature. For example, three instances are cited in Table 8 where either due to the nature of the trouser tear specimen or the 250 degrees F test temperature, it was impossible to obtain all replicate results for certain SBR compounds. A future program to resolve these tear test issues is not planned.

10. DeMattia Flex. Data for the DeMattia flex test, wherein crack length growth after 6000 c (20 min running time) is plotted for SBR and NR in Figure 12 and clearly show the extreme contrast in performance between the two base polymers. The consistently low crack growth rate of the NR compounds appears relatively unaffected by procedural or chemical modifications, while the higher SBR values fluctuate significantly dependent upon the nature of the specific variant. Values for compounds 15SBR-2, -3, -7, and -15 increased and decreased batch size, increased mixing time and higher sulfur, respectively, reached the limit of the test. Those for 15SBR-12, -13, -14, and -26, predispersed curatives, reduced Santocure, reduced sulfur, and alternate Copolymer SBR 1500, respectively, were equal to or less than that of the control. To further illustrate the relationship between DeMattia flex and processing factors, Figures 13 and 14 compare this property with T_S 1 or the time to reach a 1-lb/in. rise in Monsanto rheometer torque—an indication of the scorch rate of a compound. Here, the known parallel relationship between the two measures of potential performance is quite distinguishable. In the case of SBR, high crack growth values correspond with faster scorch rates (particularly compounds 15SBR-2, -7, and -15), while all NR compounds evidenced favorable performance and processing safety characteristics.

Referring back to Tables 10 and 11, values for the rate of crack growth after heat-aging 70 h at 212 degrees F, underscore performance differences between compounds of the two elastomers. Slight increases displayed by the NR compounds were overshadowed by tremendously accelerated growth rates for the SBR compounds, none of which survived the normally-specified 6000 c. DeMattia flex and scorch tendency are obviously related to quantity and nature of the curative/accelerator system. It is apparent that NR compounds offer some inherent advantages in this regard and that stricter controls are necessary when working with SBR compounds.

11. Goodrich Flexometer. Two parameters derived from the Goodrich Flexometer test data of Tables 10 and 11, temperature rise after 25 min running time and dynamic compression, were compared for all compounds in Figures 15 and 16, respectively. As evident in Figure 15, the temperature rise of the NR compounds is noticeably less than that of the SBR compounds' counterparts. This correlates with the known better heat build-up resistance of the former. For both polymer types, temperature rise was the least in specimens of the excess sulfur-containing compounds 15SBR-15 and 15NAT-15, while greatest for low curative compounds 15SBR-13 and -14. Other variants displaying lower heat rise were the excess volume 15SBR-2 and 15NAT-2 containing predispersed curatives. Also, in the one case where the alternate Copolymer SBR 1500 was substituted for Firestone's equivalent, the change in temperature was noticeably greater than that of the control (15SBR-26 vs. 15SBR-1).

In general, differences in dynamic compression, as shown in Figure 16, were not as significant between polymer types as was temperature rise. Patterns relative to compound variants (high and low values) were almost identical to those cited from Figure 15, and no extreme values worthy of comment were observed. Field evaluation of tank pads has evolved documentation of heat build-up exceeding 250 degrees F. Thus, determination of blowout time, also derived from the Goodrich test, is proposed for inclusion in future work.

12. Compressibility. Examination of the compressibility data as contained in Tables 12 and 13 reveals some interesting and contrasting profiles for the SBR and NR compounds, particularly when determinations were made after the three heat-aging periods. Room temperature values and those obtained after 4-h aging at 250 degrees F are quite similar for both rubbers, with the slightly lower results for NR compounds after aging indicating a greater tendency toward softening and lowered resistance to compressive forces. Results after the 70-h exposure were higher than those after 4 h for both rubbers, the comparative rise in compressive force being significantly greater for all SBR compounds. This would imply that both series had encountered a post-curing effect which was somewhat inhibited in the case of the NR compounds. The forces required to reach 40 percent compression at room temperature and after 70 h at 250 degrees F are compared graphically in Figure 17 for SBR and in Figure 18 for NR. Initially and after heat aging, lower curative levels (compounds 13 and 14) produced generally lower values, and excess sulfur (compound 15) produced the highest values. Here, curative level had the most influential effect on compressibility. When the test was repeated after the short-term combined 250-degrees-F and 300-degrees-F aging (on new specimens), values for the SBR compounds were essentially comparable to those obtained after 4 h at 250 degrees F, while those for NR demonstrated a continuation of the effects of softening or reversion, more severe than was evident after the other two aging periods. Thermocouple measurements taken in the field have documented heat build-up in tank pads to even exceed the test temperature used here. If compressibility was the prime or only property being considered, SBR would be favored. Alternate curing systems, particularly for NR which could reduce reversion and negative effects on compressibility and improve abrasion resistance, are being considered for inclusion in future studies. It is possible, as has been the subject of other investigations, that blends combining the best features of both rubbers are to be preferred when optimum overall tank-pad performance is the obvious objective.

13. Composite Data Analysis. To facilitate interpretation and analysis of the large quantity of data generated in this program, Tables 14 and 15 for SBR and NR compounds, respectively, were prepared. Here, the improvement or decrement in each of 15 of the properties evaluated was rated and assigned a symbol defined in the legend accompanying each table. The positive and negative symbols do not necessarily correlate with an increase or decrease in property values. For example, noticeably lower abrasion losses in the Taber test would receive a positive rating. Thus, the effect of a chemical or procedural change is placed in proper perspective, relative to desired performance.

Analysis of Tables 14 and 15 confirms observations noted earlier; namely, that the factors having the most significant influence on final compound properties are: overloading the Banbury mixer, extended Banbury mix time, and raising or lowering of curative and accelerator levels (compounds 2, 7, and 13 through 15, respectively). The negative effect of Banbury mixer overloading and extended mix time is more apparent in the case of SBR. While increasing the sulfur content produces some favorable property improvements in both rubbers; these are offset by declines in other characteristics such as tear strength. Reduction of the Santocure content in either rubber effected mixed changes which appear slightly more detrimental to the performance of NR. Interestingly and particularly apparent in the case of NR, a reduction in sulfur content (15SBR-14 and 15NAT-14) produced enough positive changes to indicate that the sulfur/Santocure ratio chosen for this investigation was not necessarily an optimum in terms of eliciting the best overall performance from either elastomer. An investigation of the effectiveness of alternate curative/accelerator ratios appears warranted. Consideration of entirely different vulcanization systems is a separate phase of this program and is purposely excluded from this report.

The influence of incorporating alternate forms of certain compounding ingredients does not manifest itself as readily as the factors already discussed. However, NR compounds 15NAT-9 (treated zinc oxide) and 15NAT-10 (predispersed zinc oxide) displayed significantly improved Taber and Pico abrasion values, with the latter also evidencing higher trouser tear results. Although not conclusive, these trends are sufficient to justify further evaluation of predispersed or treated additives where deemed applicable and advantageous.

IV. CONCLUSIONS

It is concluded that:

a. The performance characteristics of tank track pads can be significantly affected by extreme variations in mixing and processing as well as the type, quantity, and quality of compounding ingredients employed in their fabrication.

b. The relative effect on final physical properties of procedural deviations or changes in quality or amounts of compounding ingredients is less for NR than for SBR. This is essentially a manifestation of the chemical structure and, inherently, better processing characteristics of the former and the more reactive copolymer structure of the latter.

c. Compound mixing control variables and qualitative or quantitative formulation alternations may induce incremental or decremental changes in vulcanizate properties. True optimization of desired performance may necessitate a compromise and a trade-off of negative influences.

d. Ultimate vulcanizate properties are most significantly affected by overloading of a Banbury mixer, shortened or extended mixing cycles, and excessive temperature rise during mastication and manifested as observable characteristic surface deficiencies.

e. Use of excessive or inadequate amounts of curative and accelerator (sulfur and Santocure) results in mixed influence on specific ultimate properties of SBR and NR vulcanizates but, generally, a negative effect in terms of overall performance optimization.

f. Evidence is sufficient to justify further investigation into inclusion of predispersed or treated compounding additives to facilitate dispersion for optimizing dynamic properties. This can be done under controlled conditions; i.e., using experimental design and computerized analysis techniques. Isolation of those additives offering the best potential performance enhancement would then be possible.

g. Visual interpretation of ingredient dispersion and compound integrity, as ascertained from torn surface examination with a stereo microscope and recorded photographically by SEM techniques, correlates well with conclusions derived from physical testing of vulcanizates.

h. Within the scope of this investigation, SBR compounds exhibited better abrasion resistance than those of NR. However, use of alternate filler systems could reduce or nullify this deficiency in the latter.

i. Initial or room temperature Die C tear resistance is substantially better for NR compounds. Reduction in tear resistance at 250 degrees F is proportionately the same for both elastomers, relative to the initial values.

j. Future merit of the modified trouser tear test, based on preliminary data, is inconclusive. The highly irregular pattern displayed by NR compounds at 250 degrees F warrants further investigation.

k. SBR compounds display better tensile retention and stress relaxation properties at elevated temperatures. Further enhancement of these characteristics in both elastomers through use of alternate curing systems is possible.

l. The sulfur/Santocure vulcanization system employed in this investigation may not be eliciting the best overall performance from either elastomer. The high temperatures evolved in tank pads during operation in the field necessitate an investigation of curing systems formulated specifically to preclude reversion and other tendencies toward chemical and physical breakdown and deterioration.

m. The observed differences in properties (i.e., SBR compounds having better abrasion resistance, while NR counterparts displayed higher tear strength) justifies reconsideration of studies encompassing blends of the two elastomers or possibly so-called tri-blends with, perhaps, *cis* 1-4 polybutadiene as the third constituent. While it is probable that these blends would not draw out the best properties from each component, a highly acceptable compromise candidate is feasible.

n. Further processing studies warrant the inclusion of additional variables such as vulcanization pressure and temperature and controlled overcuring and undercuring of compounds containing currently used and alternate vulcanization systems. The objective would be to define the limits of processing safety and optimize vulcanization efficiency.

o. Additional studies could investigate more fully the use of compounding ingredients—zinc oxide, accelerators, antioxidants, and curatives, which when predispersed on an inert filler or binder are purported to facilitate mixing.

p. A minimum of four batches of a typical tank pad formulation could be mixed under controlled factory conditions to give varying degrees of ingredient dispersion. Concurrent with fabrication and field evaluation of tank pads fabricated from these batches, laboratory inspection and testing of samples taken from the production lots could be conducted. Here, the objective would be to correlate production, field and laboratory evaluations of dispersion/performance factors.

q. Other more meaningful and effective procedures for determining the degree and quality of ingredient dispersion in rubber compounds could be investigated. Possible alternates to the stereo microscope and SEM analyses would be electrical resistance measurements and a system employing a Dark Field Reflected Light Microscope in conjunction with a TV camera, waveform monitor, and an auxiliary automatic exposure photo camera. The latter system could overcome the subjectivity of existing methods through statistical analysis of resultant data.

r. Compounding studies could be conducted to evaluate known alternate curing systems purported to reduce or eliminate the reversion tendencies of NR vulcanizates. Likewise, the observed deficiencies of SBR compounds could possibly be overcome through use of similar, more specific and exotic curing mechanisms.

s. Alternate antioxidant/antiozonant systems could be evaluated relative to their potential to optimize the heat build-up and flex cracking resistance of SBR and NR compounds.

t. Investigations of alternate filler systems could also include the non-black or silica types, perhaps with silane coupling agents. These systems are known to be used in off-the-road tire compounds. When incorporated at the proper level, they have demonstrated ability to enhance properties, such as heat build-up resistance, which are desired in optimum tank pad formulation.

u. Ongoing studies directed toward compromise of the advantages of SBR, NR, and possibly polybutadiene through blending of two or all three of these elastomers could be continued. Individually, none possess all of the qualities desired in an optimum tank pad compound. Development of better, compatible, covulcanizing systems for such blends could reduce negative effects usually resulting from such compromise.

APPENDIX A
SEM PHOTOGRAPHS

Group 1

15–NAT–1A

15–NAT–1B

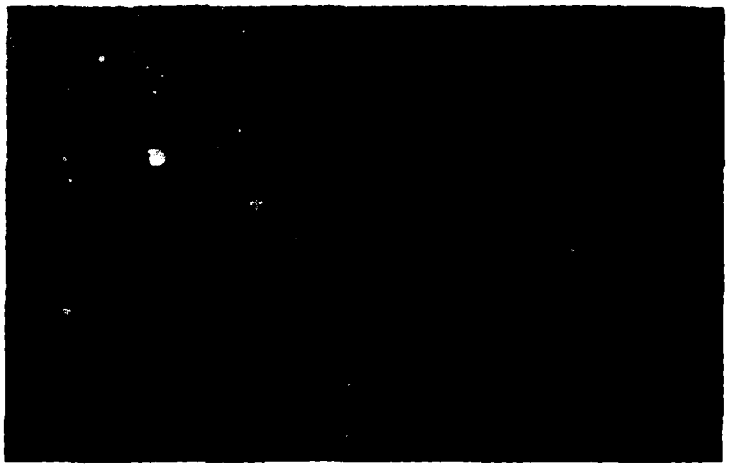
15–NAT–1C

Group 2

15–SBR–2A

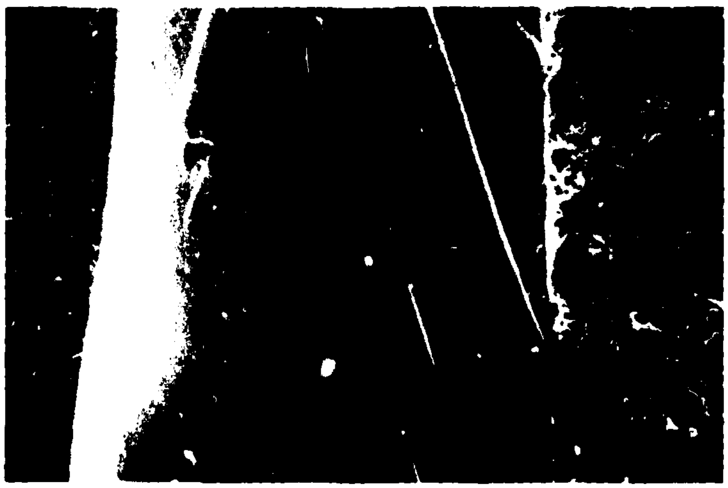
15–SBR–2B

15–SBR–2C



15–SBR–7A

15–SBR–7B



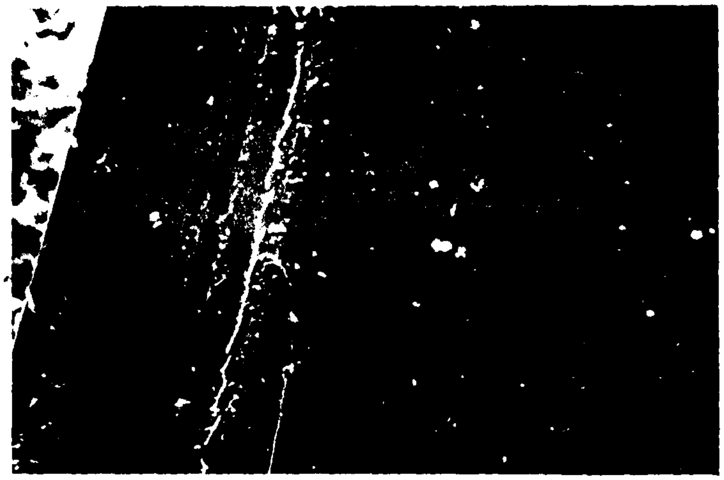
15–SBR–7C

15–NAT–8A

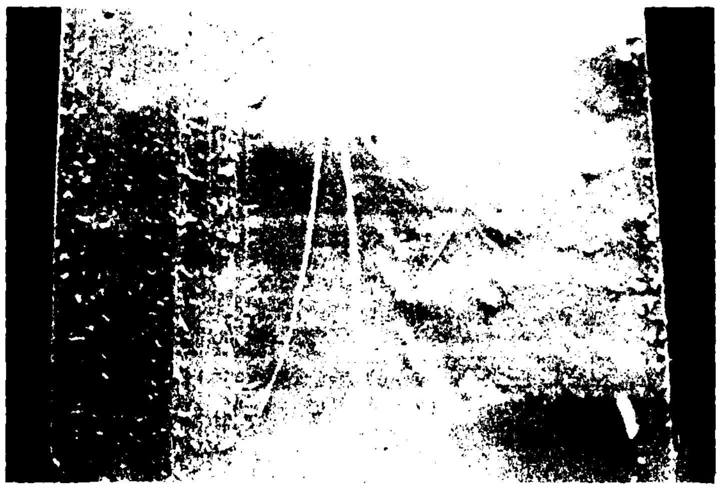
15–NAT–8B

15–NAT–8C

Group 5



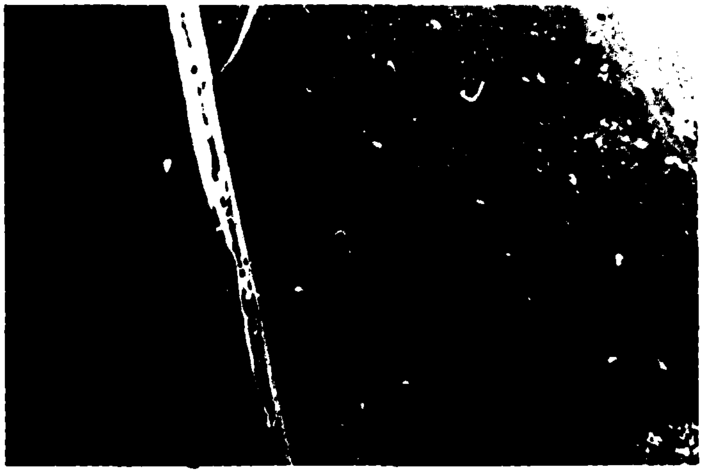
15–SBR–10A



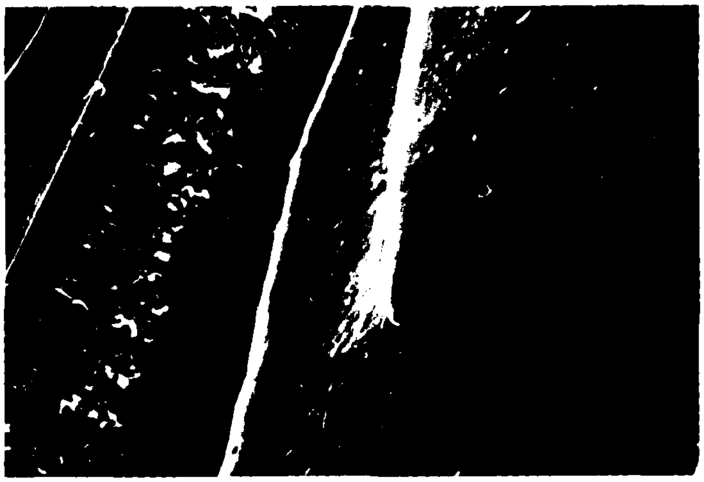
15–SBR–10B

15–SBR–10C

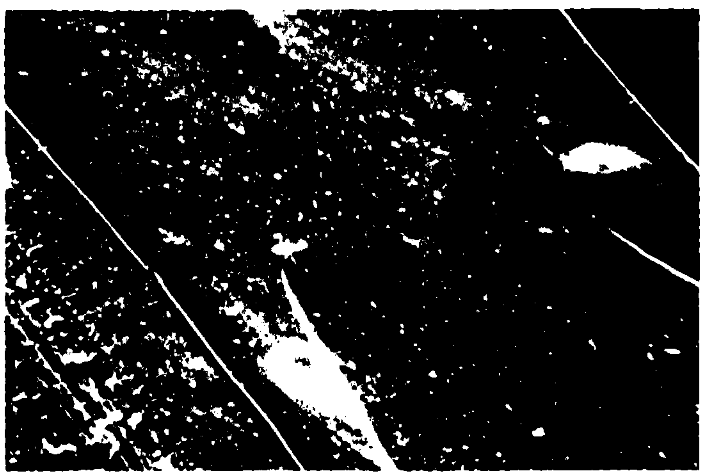
Group 6



15–SBR–15A



15–SBR–15B

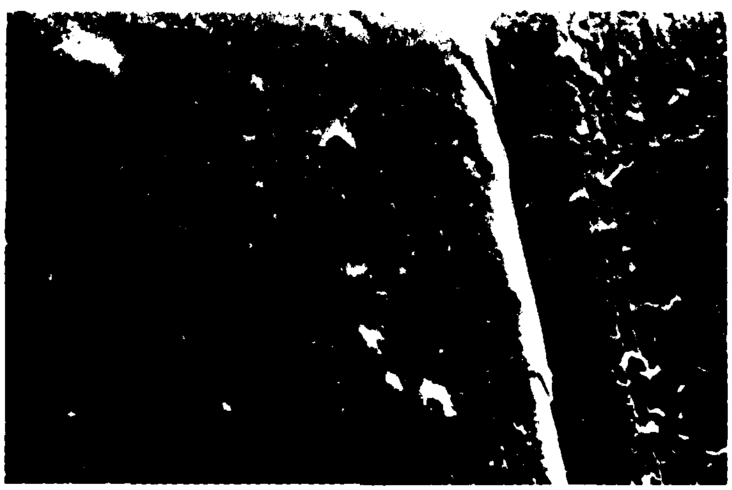


15–SBR–15C

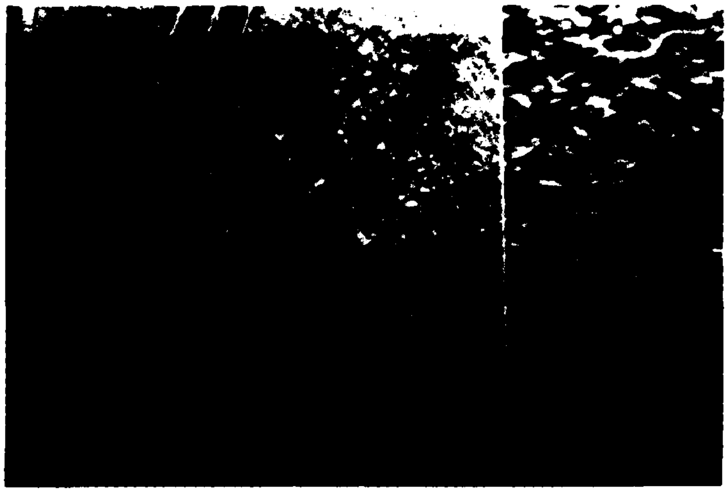
Group 7

15–SBR–16A

15–SBR–16B



15–SBR–16C



15–NAT–16A

15–NAT–16B

15–NAT–16C

APPENDIX B

CONVERSION TABLE

U.S.	to	SI
1 $lb/in.^2$	=	6.894757 kPa
lb (Avoir)	=	0.4536 kg
°F	=	9/5(° + 32)
sq in. ($in.^2$)	=	6.4516 cm^2
lb/in.	=	175.1268 N/m
in.	=	25.4 millimeters
mil	=	.0254 millimeters

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1	Dir, Resource Management Dir, STRBE-C Dir, Information Management Dir, STRBE-B Dir, Facilities and Support Dir, STRBE-W Dir, Product Assurance and Engineering Dir, STRBE-T Dir, Combat Engineering Dir, STRBE-J Dir, Logistics Support Dir, STRBE-F Dir, Materials, Fuels and Lubricants Lab, STRBE-V CIRCULATE
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